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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04N 7/20	A1	(11) International Publication Number:	WO 96/31068
		(43) International Publication Date:	3 October 1996 (03.10.96)

(21) International Application Number: PCT/US95/08160

(22) International Filing Date: 26 June 1995 (26.06.95)

(30) Priority Data:
08/409,981 24 March 1995 (24.03.95) US

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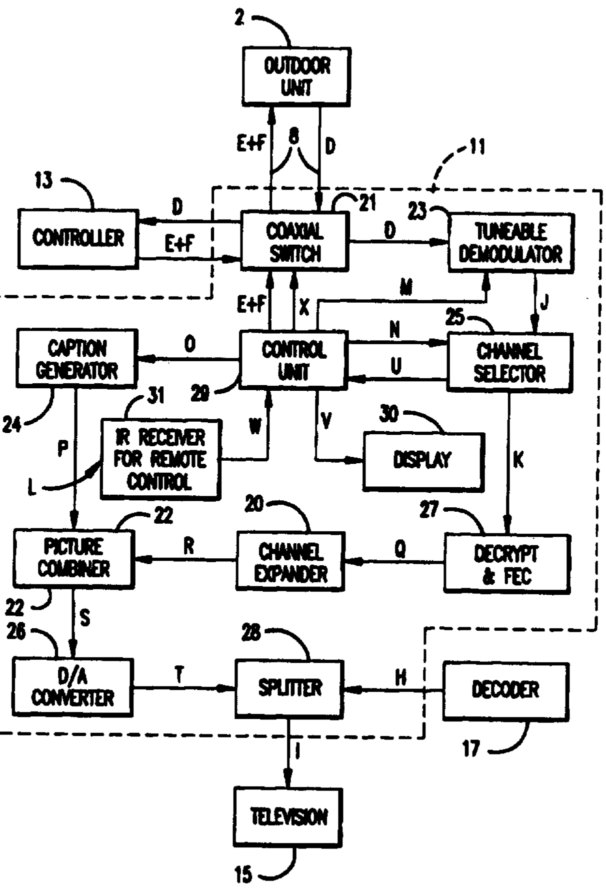
(81) Designated States: AM, AU, BB, BG, BR, BY, CA, CN, CZ, EE, FI, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LV, MD, MG, MN, MW, MX, NO, NZ, PL, RO, RU, SD, SG, SI, SK, TJ, TM, TT, UA, UG, UZ, VN, ARIPO patent (KE, MW, SD, SZ, UG), European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: ADAPTER MODULE FOR DIRECT-TO-HOME TELEVISION BROADCAST RECEIVING SYSTEM

(57) Abstract

An adapter (11) for a direct broadcast television system enables owners of existing dish antennas to receive both current analog television broadcasts and new digital broadcasts via C-Band satellites. The adapter includes a coaxial switch (21) for switching between analog and digital television, a tuneable demodulator (23) for selectively switching between transponders on the C-Band satellites, a channel selector unit (25) for selecting the channel specified by the user from the bit stream output by the demodulator, a channel expander (20) for decompressing the video signal, and a control unit (29) for accepting user commands and controlling the polarization of the received signals, the steering of the TVRO antenna (1), the demodulated transponder frequency and the demultiplexed channel. The ability to select the user's channel from multiple channels available on different transponders and different satellites allows the dynamic reassignment of television channels based on system efficiency considerations. The adapter is able to simultaneously serve analog and digital TV to both cable and TVRO and C-Band small antennas and enables a smooth, seamless conversion to digital C-Band receivers with only one box. The adapter may be advantageously used in conjunction with a C-Band or Ku-Band satellite communication system which uses a relatively small receiving antenna while operating within current FCC designated bandwidth and using existing satellite configurations.



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ADAPTER MODULE FOR DIRECT-TO-HOME TELEVISION BROADCAST RECEIVING SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates generally to converters for direct-to-home (DTH) satellite broadcast television systems, and more particularly to a converter for a DTH satellite broadcast television system for receiving C-band broadcasts.

Currently, about 4 million households in the United States employ a large television receive only (TVRO) satellite dish antenna for receiving C-Band television broadcast programming. These antennae receive transmissions in analog format from a constellation of C-Band geosynchronous satellites, which relay television programs from groundstations to the TVRO dish antennas. The existing C-Band broadcasting systems employ a converter (or receiver) located near the television to output a television channel specified by the viewer to a television or video cassette recorder (VCR). The converter is connected to the TVRO dish via a long coaxial cable that runs from the converter to the equipment (termed the outdoor unit) mounted outside near the TVRO dish. The coaxial cable may in addition be assembled with other cables and signals, at least one of which carries a control signal to the antenna to select the polarization of the RF signals, since the RF signals transmitted from the satellite are either vertically or horizontally polarized. The coaxial cable may also be assembled with a cable that carries a control signal to the antenna to steer the antenna from inside the house. Since these TVRO dishes are large, automatic steering is often used to avoid the inconvenience of climbing on the roof and resteering the antenna if broadcasts from a different satellite are desired.

While digital technology has been in use in telecommunications for some time, its use has been mostly limited to voice and data applications, until recently. Converting voice-grade signals into a digital format was relatively easy, but the task of digitizing video signals efficiently presented a much greater technological challenge.

Video signals that are digitized but not compressed require high bit rates. Consequently, they use the same amount or more of RF spectrum bandwidth as the analog formats they were attempting to replace. While other benefits would ensue from simply converting analog video signals to digital video signals, such as improved quality, the resulting increase in bandwidth and power from this conversion would increase satellite costs dramatically.

The advent of digital chip technology and sophisticated video data compression algorithms makes it possible for broadcasters to squeeze a digital video signal into far less spectrum bandwidth. Multiple video signals that were compressed using these data compression algorithms can now fit into the bandwidth reserved for a single analog video signal. Thus, the cost of satellite distribution decreases because less bandwidth is required for each video feed. Consequently, digital television is or soon will be available to the public. Unfortunately for the owners of the large TVRO satellite antennas, the advent of digital television may make their TVRO dishes obsolete, i.e., they must now buy new antennas and systems for receiving the new digital television, which is currently being broadcast at frequencies different from that for which these TVRO antennas are designed. The owners of these dish antennas invested upwards of $2500 in their systems, and are less likely to reinvest a similar amount in a new system. Therefore, a transition from analog TV to digital TV will prove to be an expensive proposition for these TVRO dish owners.

The present invention is therefore directed to the problem of developing a converter for use in a direct broadcast television system that will allow simultaneous reception of new digital C-band television and the current analog television signals, without requiring a major investment by the current users of analog television received via TVRO satellite antennas. The present invention is therefore directed to the problem of developing a dual converter that will receive both analog and digital TV so that a smooth and inexpensive transition from analog to digital TV is possible. Furthermore, the present invention is directed to the problem of providing a converter that provides complete flexibility to the broadcast system operator when assigning satellite resources, yet will provide a smooth transition from analog C-Band television to digital C-Band television.

SUMMARY OF THE INVENTION

The present invention solves this problem by providing a converter that receives the format of the new digital television signals, passes the existing analog television signals to an existing receiver, and outputs the desired TV signal to the television, without requiring the user to install a new satellite antenna, or to give up his current system.

The converter of the present invention is coupled between a video device, such as a television or VCR and a receiver for receiving existing analog C-Band broadcast television signals. The converter permits simultaneous reception of both the existing analog television signals and digital C-Band broadcast television signals using a single receiving antenna. To do this, the converter includes a control unit with two operating modes. The control unit receives mode commands from the user for switching the converter into either the analog operating mode for receiving the existing analog television signals or into the digital operating mode for receiving the digital C-Band broadcast television signals. The control unit receives a digital channel selection command from the viewer indicating which digital television channel should be output in the digital operating mode, and outputs a digital channel selection signal, and a transponder selection signal. The converter employs a switch with one input coupled to the outdoor unit for receiving an intermediate frequency (IF) signal output by the outdoor unit, one output coupled to the receiver, and a control input coupled to the control unit, whereby the control unit controls the switch via the control input so that the IF signal is output to a second output in the digital operating mode and the IF signal is output to the first output in the analog operating mode. The converter also includes a demodulator coupled to the second output of the switch, which demodulator receives the IF signal in the digital operating mode, receives the transponder selection signal from the control unit, and demodulates the transmitted bit sequence from the IF signal at the carrier frequency specified by the transponder selection signal. The converter also includes a channel selector, which receives the bit sequence from the demodulator, receives the digital channel selection signal from the control unit, and demultiplexes the bit sequence to form the selected compressed digital television signal. The converter also includes a channel expander, which receives the selected compressed digital television channel and decompresses the selected compressed digital television signal to form the selected digital television signal. A digital-to-analog converter receives the selected digital television signal and converts the selected digital television signal into the analog television-ready signal. An output coupler e.g., coupled to the video device, receives the analog television-ready signal (e.g., NTSC formatted signal) from the digital-to analog converter in the digital operating mode, and receives an additional analog television-ready signal from the receiver for receiving the existing analog C-Band broadcast television signals in the analog operating mode, and outputs the analog television-ready signal from the digital-to analog converter in the digital operating mode and outputs the additional analog television-ready signal in the analog operating mode.

An advantageous embodiment of the present invention provides that the control unit outputs a polarization select signal to the receiver for receiving the existing analog C-Band broadcast television signals to change a polarization of the RF signal received by the antenna.

Another advantageous refinement of the present invention provides that the channel selector outputs a data management channel transmitted on each transponder to the control unit, which data management channel contains information regarding programs available on all digital television channels on all satellites and transponders transmitting the digital C-Band broadcast television signals. The data management channel also includes a menu of future programs identified by network ID as well as a content identifier. The content identifier provides a description of the program. The channel "name" provided to the viewer is coupled with the satellite transponder, polarization and frame.

Yet another advantageous embodiment provides that several digital television signals are modulated on each transponder carrier signal using a minimum shift keying modulation technique, and that the demodulator demodulates the RF signal using a minimum shift keying demodulation technique.

Still another advantageous embodiment of the present invention provides that several digital television signals are transmitted by each transponder on each C-Band satellite using one polarization and other digital television signals are transmitted by another transponder in the same radio frequency spectrum on said each C-Band satellite using another polarization, which is orthogonal to the first, and the control unit transmits a polarization select signal to the receiver for receiving the existing C-Band broadcast television signals based on the digital channel selection command received from the user, which polarization select signal determines which polarization the RF signal received by the antenna contains.

Another advantageous embodiment provides that a first RF signal containing several digital television signals is transmitted by one C-Band satellite and a second RF signal containing other digital television signals is transmitted by another C-Band satellite, and the control unit transmits a satellite steering control signal to the receiver based on the digital channel selection command received from the user, which satellite steering control signal determines whether the first RF signal or the second RF signal is received by the antenna.

Another advantageous embodiment provides that each C-Band satellite that is broadcasting digital television channels can dynamically reassign each digital television channel to any transponder on said each C-Band satellite, using any polarization and in any channel location within its multiplexing scheme, and the control unit dynamically modifies the polarization selection signal, the digital channel selection signal and the transponder selection signal based on the program "network" identity information contained in the data management channel to cause the channel selector unit to output the digital television channel specified by "network" name by the viewer via the digital channel selection command.

Another advantageous embodiment provides that the control unit includes a storage unit storing default values and menus of future programs for each digital television channel available on all satellites and all transponders. The default values include a satellite indicator, a transponder indicator, a polarization indicator, and a bit frame assignment as well as the time of the programs. The control unit regularly updates these default values based on information included in the data management channel.

Another advantageous embodiment provides that a caption generator is included, which is coupled to the control unit. The caption generator receives a text message signal from the control unit and outputs a video text signal representing the text message. A picture combiner is coupled to the caption generator and the channel expander, which combiner receives the video text signal from the caption generator and the selected digital television signal from the channel expander and combines the video text signal and the digital television channel into a combined text and video signal.

Another advantageous embodiment provides that a display is included, which is coupled to the control unit for displaying the selected digital television channel number to a viewer.

The present invention also specifies a method for receiving both existing analog C-Band satellite broadcast television signals and digital C-Band satellite broadcast television signals using a single receiving antenna, an existing device for receiving the analog C-Band satellite broadcast television signals and an adapter module coupled to the receiving antenna and the existing device, in which a first plurality of digital television channels are multiplexed into a first bit sequence, a second plurality of digital television channels are multiplexed into a second bit sequence, the first bit sequence is modulated on a first carrier signal and transmitted from a first transponder on a particular C-Band satellite using a first polarization, the second bit sequence is modulated on the first carrier signal and transmitted from a second transponder on the particular C-Band satellite using a second polarization, and the first and second bit sequences also include a data management channel specifying a satellite, a carrier frequency, a polarization and a bit frame assignment for all available digital television channels, including digital television channels being transmitted from other C-Band satellites. The method includes the steps of: (a) switching the adapter module to either an analog reception mode or a digital reception mode based on a mode reception command from a viewer; (b) in the analog reception mode: (i) controlling a switch in the adapter module to couple the received RF signal containing the analog C-Band satellite broadcast television signals from the receiving antenna to the existing device; (ii) receiving a television-ready signal from the existing device; and (iii) providing the television-ready signal as an output from the adapter module; and (c) in the digital reception mode, (i) receiving a digital television channel selection command from a viewer specifying a particular digital television channel to be provided as an output from the adapter module; (ii) determining the carrier frequency, the polarization, and the bit frame assignment for the particular digital television channel based on information contained in the data management channel; (iii) controlling the receiving antenna so that the receiving antenna outputs a polarized RF signal having the particular polarization; (iv) controlling the switch so that an IF signal corresponding to the polarized RF signal is coupled to a demodulator; (v) controlling the demodulator so that the demodulator demodulates the IF signal at the particular carrier frequency to form a bit sequence; (vi) controlling a channel selector so that the channel selector demultiplexes a compressed version of the digital television channel from the bit sequence output by the demodulator based on the particular bit frame assignment; (vii) restoring the compressed version of the particular digital television channel to the particular digital television channel; and (viii) converting the particular digital television channel to a television-ready signal.

A refinement of the method of the present invention provides that default values of present and future programs are used for the polarization, the transponder carrier frequency and the bit frame assignment, when first switching from the analog reception mode to the digital reception mode, and updates are obtained by reading the data management channel using the default values to determine the correct values for the polarization, the transponder carrier frequency and the bit frame assignment for the selected digital television channel. In this refinement, default values are stored for the polarization, the transponder carrier frequency and the bit frame assignment in the adapter module. Upon first switching from the analog reception mode to the digital reception mode, the control unit updates the default values dynamically with information contained in the data management channel as long as the adapter module remains in the digital reception mode.

Another method of the present invention permits a smooth transition from analog C-band television service to digital C-band television service and then to digital C-band television service to a small receiving antenna. According to the method of the present invention, only a few transponders are converted at first to digital service. Each transponder transmits multiple compressed digital television channels, as well as a data management channel. The data management channel (DMC) contains information regarding all channels available on the digital service, e.g., the satellite, the transponder, the polarization and the frame assignment, as well as present and future programming available on each digital TV channel. Those users with existing TVRO dishes would be able to receive these signals if they used an adapter, as discussed previously. To transition to digital C-band service to small antennas, the data rate on each transponder must be decreased. To do so without reducing the total number of digital TV channels, additional transponders are converted to the digital service. By simply moving some channels to new transponders and updating the DMC, the user is unaffected by such a change. Thus, a smooth transition to digital C-band service from analog C-band service is possible, as well as a smooth transition to digital C-band service to small antennas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG 1 depicts an antenna for use in a C-Band satellite communication system.

FIG 2 depicts a typical antenna pattern of a normal three foot dish antenna receiving signals from the current constellation of television broadcast satellites operating in the C-Band range.

FIG 3 depicts the distance travelled by all rays from the feed-horn to the reflector to the target satellite, when the direction to the target satellite lies along the main axis of a parabolic antenna.

FIG 4 depicts the distance travelled by all rays from the feed-horn to the reflector to the target satellite, when the direction to the target satellite lies not along the main axis of a parabolic antenna, but rather lies along a path offset from the main axis.

FIG 5 depicts the signal strength of the received signal on the surface of a C-Band antenna, as seen from a top view of the antenna.

FIG 6 shows the projection of energy arriving at a C-Band antenna from the satellite 2.24° from the central satellite.

FIG 7 shows the projection of energy arriving at a C-Band antenna from the satellite 4.48° from the central satellite.

FIG 8 shows the projection of energy arriving at a C-Band antenna from the satellite 6.72° from the central satellite.

FIG 9 depicts the received signal strength from the off axis satellites of a C-Band antenna.

FIG 10 depicts a satellite portion of a satellite communication system operating in C-Band.

FIG 11 depicts a ground station portion of a satellite communication system.

FIG 12 depicts a cross-section of a C-Band antenna and the corresponding received signal strength.

FIG 13 depicts a general view of a C-Band antenna.

FIGs 14a-14c are graphs of the cross-section of the dish along F'-E-F (or G'-E-G) in FIG 13, in side view, plan view and right view.

FIG 15 depicts a satellite receiving a signal and retransmitting the signal back to earth.

FIG 16 depicts a system employing the adapter of the present invention to receive both analog and digital C-band television using an existing outdoor unit and parts of an existing indoor unit.

FIG 17 depicts a block diagram of one embodiment of the adapter of the present invention, as shown in FIG 16.

FIG 18 depicts a rear view of the adapter module of the present invention.

FIG 19 depicts the front face of the adapter module of the present invention.

DETAILED DESCRIPTION

The present invention discloses a system for transmitting and receiving both analog and digital C-band television by existing TVRO parabolic dish antennas. In addition, the architecture of the system permits the operator of the system to dynamically assign digital television channels among the available resources to optimally use these resources. By providing a simple and inexpensive adapter module to permit existing TVRO dish antennas to receive digital television broadcasts, the present invention permits a smooth transition from analog C-band television to digital C-band television, and to digital C-band television for reception by a small receiving antenna. The features that permit these advantages are set forth below.

ANALOG TV BROADCAST SYSTEM

Currently, there are 18 C-Band satellites in geosynchronous orbit broadcasting analog television channels to about four million owners of TVRO dish antennas in the United States. Each of these satellites employs 24 transponders (12 in each of 2 polarizations) in C-Band (3.7 GHz to 4.2 Ghz downlink frequency band), with each transponder signal being modulated by a television signal having a bandwidth of 36 MHz. Replacements for these satellites which have yet to be launched will have 36 transponders (18 in each of 2 polarizations), since more frequency bandwidth has been made available by the Federal Communications Commission. Each modulated carrier signal contains one analog television channel. The satellites use one feed to radiate an RF signal having one form of polarization, such as left-hand circular, or vertical, and another feed to radiate another RF signal using a polarization that is orthogonal to the other, such as right-hand circular, or horizontal, respectively. Consequently, there will be about 432 (18 x 12 x 2) analog television channels potentially available for reception by these TVRO dishes.

The particulars of the analog television broadcast signal format need not be described in detail here. It is sufficient to state that existing receivers for C-Band television broadcast signals transform these signals into television ready signals, which are usually NTSC formatted signals.

In the analog reception mode, the present invention provides that the RF signals received by the existing TVRO dishes will be relayed without modification to the existing equipment. The resulting television signal output by the existing equipment will be then relayed to the television also without modification. The details of this portion will be described below with reference to FIG 16.

DIGITAL TV BROADCAST SYSTEM

U.S. Patent Application No. 08/259,980, hereby incorporated by reference in its entirety, describes an invention that recognized that digital compression techniques permitted a reasonable tradeoff between the number of television channels being transmitted per satellite transponder and the receiving antenna size. Recently developed video compression algorithms permit a possible tenfold increase in the number of digital television channels that can be transmitted in the current bandwidth provided for analog television. Although providing users with ten times as many television choices might on its surface appear desirable, viewers may be overwhelmed with the number of choices available in such a system. For example, simply reviewing the choices available in a system of 4320 channels would take hours. Therefore, trading off some of the increase in the number of possible television channels for some other benefit might not be all that unreasonable. In fact, by reducing the number of television channels being transmitted over the same bandwidth, i.e., spreading less information bits over the same bandwidth, a reduction in the sensitivity of the receiving antenna is possible.

One manifestation of this reduction in receiving sensitivity is a reduction in the surface area of the ground antenna. Consequently, the system described in U.S. Patent Application No. 08/259,980 permits a C-Band receiving antenna having the surface area of a three foot parabolic dish. The disclosure of the small receiving antenna in U.S. Patent Application No. 08/259,980, hereby incorporated by reference in its entirety, teaches the following.

Background of the Reduced-Size Receiving Antenna

Television has evolved from a local broadcasting concept to a system in which a viewer may receive television signals from a variety of sources. Today, television viewers receive programming from at least one of several different methods, such as direct "over-the-air" broadcasts from local television stations, transmission over land cables, i.e., cable television (CATV), transmission over microwave systems, and direct to home (DTH) broadcast via satellite.

Television viewers may receive DTH satellite broadcasts by purchasing home satellite dish equipment, however, current satellite television communication systems operate with receiving antennas that are relatively large, e.g., on the order of 10 feet in diameter or more for current C-Band parabolic dishes. At lower satellite frequencies the receiving dishes are even larger.

The consequences of large receiving antennas affect the very nature of the type of service provided via satellite. Large dishes require a concrete pad for support, large amounts of space, installation by trained technicians and complicated positioning mechanisms due to the weight of the antenna, all of which translate to high costs for the initial installation. The high installation costs directly impact sales as many consumers cannot afford these high installation costs.

While cost is a large factor, it is by no means the only disadvantage of current DTH satellite service. Many consumers dislike the aesthetics of a large satellite dish sitting in their yard. Consequently, many consumers who could otherwise afford to subscribe to current DTH service do not subscribe because they do not want to place a large parabolic dish antenna in their yard. Due to the poor aesthetics of these antennas, restrictive covenants in housing developments often prohibit home owners from erecting them.

The combination of high costs and low aesthetics of these antennas limits the appeal of DTH satellite broadcasts, which directly competes with current

CATV providers, hence the growth of CATV has been comparatively explosive due to lack of effective competition. However, CATV will probably never be available to all consumers due to its high installation costs in rural areas. Furthermore, the high costs of CATV installation means that many third world countries will not get CATV for many years, if ever. Thus, there will probably always be a market for DTH satellite services.

Even if the costs and aesthetic problems were solved, large antennas are not practical. While large dish antennas may be suitable for use in some applications, they are much too large for general home consumer use, or at least for use in most homes. The problem is particularly acute in urban areas, where it would be impractical for everyone to employ such a large antenna due to space limitations. As a result, CATV enjoys a relative monopoly on television services in urban areas.

In some parts of the world, other DTH services called Direct Broadcast Services (DBS) are available. The major advantage of these systems is they transmit signals at Ku-Band frequencies, which are higher than C-Band frequencies. Higher transmitting frequency permits a smaller receiving antenna, which for Ku-Band systems is on the average about 3 feet in diameter.

While higher frequency signals permit smaller receiving antennas, even these antennas can be too large for some applications where space is at a premium. Thus, there is a need for reducing the size of television antennas, particularly at lower satellite frequencies, such as C-Band frequencies or lower.

In addition, the demand for television services from satellites has caused the Federal Communications Commission (FCC) to approve narrower spacings in the synchronous orbits, about 22,000 miles above the earth's equator. The use of ±2° spacing allows many satellites to supply television service to the U.S. market. As more and more DTH services become available, demand will cause further reductions in satellite spacing, making the problem of interference from adjacent satellites more acute.

Previously, it was believed that C-Band satellites because of their power limitations and close spacing (about ±2°) in a synchronous satellite orbit were limited to receiving antennas at least 8 feet in diameter, and in most areas, commonly 10 feet to 15 feet in diameter. These large antennas are commonly used today, and more than 4 million such antennas are installed throughout the United States. These antennas receive television programs from up to 18 satellites. If satellite spacing reduces further, larger receiving antennas will be required to discriminate between the desired satellite and its closest neighbors.

Prior to the invention disclosed in U.S. Patent Application No. 08/259,980, the only way to reduce the size of the receiving antenna for DTH systems to something below three feet in diameter was to use a higher radio frequency band, such as Ku-band (about 17 Ghz), which is allocated by the FCC for direct broadcast services (DBS). In this radio band, the FCC permits higher power satellite transmissions, which translates to a reduction in the required antenna size. The higher frequency also results in a smaller width of the antenna sensitivity beam, as a result of the relationship between the width of the beam and the radio frequency. For example, a two to three foot diameter antenna operating at Ku-band frequencies, using a beam width of approximately 1.3° to 1.5°, typically can achieve an antenna sensitivity pattern that is sufficient to isolate signals from satellites that are ±2° from the targeted satellite.

The move to higher frequency, however, comes at the cost of a need for even higher transmission power due to rain absorption at these higher frequencies. Rain has two effects on radio waves passing through it. Rain scatters the energy so that less of the energy reaches the receiver, and rain radiates thermal energy that reaches the receiver, thus increasing the random noise that interferes with the received signals. The amount of absorption and increased thermal noise from scattering is more severe for radio signals at higher radio frequencies and therefore with shorter wavelengths. The overall effect of rain loss depends on the level of rain expected and the reliability required for the service. For typical reliability levels of DTH service, at Ku-Band frequencies, one must increase the radiated power by a factor of ten to allocate for rain loss. About one third of the increase is due to increased noise and two thirds is due to rain absorption. For lower level frequency bands, such as C-Band, the corresponding allocation of power increase for the same level of reliability amounts to only about 30%.

By increasing the satellite transmission frequency to Ku-Band, higher power can be transmitted from the satellite, and a smaller antenna will achieve the required isolation for a ±2° satellite spacing. For example, a three foot antenna operating at Ku-Band has a beam width of approximately 1.8°. However, Ku-Band also requires a tenfold increase (1,000%) in transmitted power to overcome losses due to rain. At C-Band an increase of only 30% is typically needed for rain loss. Thus, merely moving to a higher frequency does not necessarily solve all the problems with antenna size.

In addition, to implement a small receiving antenna using existing C-Band satellites would seem to violate basic limitations on power and beam isolation. The restriction on total satellite power is set by the FCC at -152 dBW/m^2 per 4 Khz bandwidth power flux density reaching the ground. The FCC limits vary with frequency. A higher power is permitted at Ku-Band frequencies. In fact, no limits exist for frequencies in the Ka-Band. The FCC limits are designed to protect ground microwave relay equipment from interference by satellite transmissions. Obviously, foreign governments have their own limits on radiated power. The present C-Band satellites operate with radiated power up to approximately 36 dB EIRP, which falls just below the FCC limit when reaching the ground. The normal way to achieve a ground station antenna area reduction is to increase the satellite power by an equal amount. A reduction from a nine or ten foot satellite antenna to a three foot antenna would normally require a tenfold increase in satellite power, which would significantly exceed the FCC imposed limits by approximately a factor of ten.

Reducing the antenna size and increasing the transmission power, even if permitted by the FCC, would not completely solve the problem because a small receiving antenna has a larger directional receiving range. A smaller antenna of normal design will receive the signal from the satellite of interest, but will also receive interfering signals from other satellites in the constellation, at least as currently configured in the C-Band system, for example. The received signal will thus be so distorted as to impair proper decoding and reception.

Thus, the other barrier to antenna size reduction is a corresponding increase in the beam width of the receiving antenna. Current eight foot C-Band antennas have beam widths typically of 1.8°, which is sufficient to discriminate between satellites ±2° away in orbit. A normal three foot antenna has a beam width of approximately 4.9°, which is not sufficient to discriminate against satellites at ±2° from the targeted satellite.

The power and beam width limitations are the main barriers that have prevented the industry from offering television services to small antennas at C-Band, which has in turn limited the growth of the DTH industry. To offer DTH service to small C-Band antennas, both power and beam width problems must be solved simultaneously.

Thus, the disclosed invention is directed to the problem of solving the power and beam width limitations necessary to reduce the size of the receiving antenna in a satellite communication system. The disclosed invention is also directed to the problem of developing a satellite communication system that permits the use of a relatively small receiving antenna, yet operates within the current FCC power limitations and with existing satellite configurations, which system will operate in at least C-, Ku-, S-, L- and Ka-Bands. The disclosed invention is also directed to the problem of developing a terrestrial antenna for use in the above communication system that is relatively small, yet permits reception from existing satellite communication systems, without requiring a change in the FCC satellite transmission power limitations or a change in orbital locations of the satellites. Finally, the disclosed invention is directed to developing the components for use in the above mentioned communication systems.

<u>Summary of the Reduced-Size Receiving Antenna</u>

The invention disclosed in U.S. Patent Application 08/259,980 solves these problems by using a combination of: (1) aperture synthesis to create nulls in the antenna pattern that correspond to orbit locations from which potential interference is expected; (2) spectral shaping techniques to reduce transmission power flux density and interference; and (3) video compression techniques to reduce the power necessary to transmit video information. As used herein the term nulls refers also to minima in the antenna pattern, i.e., places where the antenna pattern achieves minimum values. The combination of these three techniques permits the use of an antenna with a receiving area equal to that of a three foot antenna at C-Band frequencies, and antennas with receiving areas that are significantly smaller than what is currently available for Ku-, S-, L- and Ka-Band frequencies, as well as other frequency bands.

In fact, the disclosed invention permits a reduction in receiving antenna area, from what is currently available, for any signal being transmitted from a satellite within a constellation of satellites, particularly where a reduction in receiving antenna area would cause the receiving antenna to be unable to discriminate between satellites in the constellation. Furthermore, the disclosed invention allows a receiving antenna to discriminate between a desired signal and potential noise sources, where the desired signal and potential noise sources have predetermined physical locations with respect to each other.

The exact implementation of the aperture synthesis technique varies slightly in the different frequency band systems, whereas the video compression technique and spectral shaping technique remain generally the same. Each technique will be separately described, and then also set forth in an embodiment for a particular application, such as C-, Ku-, Ka-, L- and S-Band.

Video Compression

The same video compression technique applies to all systems described herein, since the video compression used allows a reduction in transmission power by a factor of ten, regardless of the transmission frequency by reducing the required data rate by the same factor. While the video compression technique used in the satellite communication system by itself does not form part of the disclosed invention, its use in combination with the aperture synthesis and spectral shaping, as well as the components that result from such a use, are novel. The disclosed invention employs a commercially available video data compressor available from Scientific Atlanta. The compression technique required need not be this precise product, but may be any technique that achieves at least the same reduction in data rate. Obviously, as compression techniques improve, further reductions in transmission power will be possible, thus further enabling a corresponding reduction in the size of the antenna, or a reduction in the radiated power, or perhaps an increase in the number of transmitted channels.

Spectral Shaping

Another component of the invention disclosed in U.S. Patent Application 08/259,980 that allows rapid implementation of small antenna service is the deliberate choice of spectrally inefficient modulation. The data rate of digitally compressed video is three to five megabits per second (3-5 MBPS). This data rate could easily be transmitted in a radio frequency bandwidth of 5 MHz or less, using an efficient modulation choice, such as Quadrature Phase Shift Keying (QPSK) or Quadrature Amplitude Modulation (QAM). However, use of QPSK or QAM would for some C-Band satellites violate the power flux density limitations set by the FCC, due to the high spectral density of these modulation schemes. In addition, the use of QPSK or QAM could also possibly upset coordination between satellites now used by the industry to avoid inter satellite interference.

The disclosed invention uses a Shaped Frequency Shift Key (SFSK) modulation scheme to keep the energy of the transponder spread smoothly over the bandwidth of the satellite transponder, e.g., spread over the 30 MHz for current C-Band satellite transponders. By spreading the bandwidth from 5 MHz to 30 MHz using the SFSK modulation technique, the power density lies below the FCC limits. The spectrum, if anything, is smoother than the spectra in the present satellites and thus will cause less interference to users of other transponders in nearby satellites. By using SFSK modulation, in combination with video compression, the radiated power of the communication system meets the FCC power flux density limitations. Yet, the disclosed invention also permits a quick and simple transition from current service using existing transponders to the system of the disclosed invention without any increase in interference to other users and without requiring new satellite launches.

By choosing the optimum demodulation technique, the receivers of the disclosed invention are also less susceptible to interference from adjacent satellites, whether the other satellites carry signals that are different than the SFSK signal of the disclosed invention, or carry the same signal as the SFSK signal of the disclosed invention. The SFSK signals themselves have a "coding gain" (or protection) approximately equal to the transponder bandwidth divided by the data rate. This amounts to a protection factor of between three and ten depending on the number of television signals of the disclosed invention in one satellite transponder.

For example, where the data rate is between 3-5 MBPS and the available bandwidth is 30 MHz, the gain becomes:

$$G = \frac{B\,(Hz)}{r\,(bits\ per\ \sec)} = \frac{30\ MHz}{3\ MBPS} = 10 \qquad (1)$$
$$G = \frac{B\,(Hz)}{r\,(bits\ per\ \sec)} = \frac{30\ MHz}{5\ MBPS} = 6$$

This coding gain is not spread spectrum gain but is more related to earlier frequency coordination techniques. It is basically determined by Shannon's Law, which relates the data rate, r, to the bandwidth of the modulated signal, B, by the relationship:

$$\frac{r}{B} \le \log_2\left(\frac{C}{N} - 1\right) \qquad (2)$$

where C/N is the ration of carrier power to noise power needed to receive the signal. By itself, the use of SFSK modulation is not sufficient to protect against adjacent satellite interference, but is does form part of the overall protection of the disclosed invention by reducing the requirements of the depth of the antenna sensitivity nulls and pointing accuracy required of a small antenna.

Three different SFSK modulation shapes are available, depending on whether the transponder of the disclosed invention uses one, two or three channels, which depends on the radiated power available in the transponder. A transponder radiating 30-31 dB EIRP can transmit one television channel using one particular SFSK shape; a transponder radiating 31-33 dB EIRP can transmit two channels using a different SFSK shape; and a transponder radiating 35 dB or more EIRP can transmit three channels using a third shape, which is different than the other two. The choice of specific SFSK shape ensures that the present invention is non-interfering with present satellite users and non-interfering with itself.

While SFSK modulation is known, and does not by itself form part of the disclosed invention, the combination of SFSK modulation, video compression and aperture synthesis is novel.

The adjustment of data rate with EIRP, while keeping the bandwidth constant and yet automatically accounting for the reduction in transmitted power by providing additional protection through the choice of SFSK modulation is also novel. Decreasing the radiated power for the same bandwidth, while simultaneously decreasing the data rate, effectively increases the "coding gain". Thus, the disclosed invention automatically provides additional protection from interfering signals. The result is that maximum channel capacity is achieved with a given size antenna but unequal satellite EIRP's. For example, an interfering satellite with 35 dB of radiated power would be three times more interfering to a satellite with a 30 dB EIRP, but the coding gain of the receiver for the 30 dB satellite would have three times the coding gain to compensate.

Aperture Synthesis

The invention of U.S. Patent Application 08/259,980 employs an aperture synthesis technique to permit a small antenna to discriminate between a satellite within a constellation of satellites, despite the fact that its beam width is wider than the spacing of the satellites in the constellation. Aperture synthesis refers to shaping the antenna not in a circle but in an irregular shape that puts nulls in the antenna pattern that correspond to precisely the orbit locations from which interfering signals are expected to originate.

The aperture synthesis technique of the disclosed invention places gaps in the antenna surface to cause signals from satellites other than the targeted satellite to cancel themselves out, while enhancing the non-interfering signals. The exact design of the antenna will differ for each frequency band for which it is implemented, however, the basic concept remains the same. By matching the gaps in the receiving antenna to the point at which the signals from adjacent satellites will impinge upon the receiving antenna, such that the interfering signals will cancel themselves out, the antenna effectively places notches in its beam width where interfering satellites are located.

The use of aperture synthesis to create nulls in the receiving antenna such that the antenna cancels out interfering signals from adjacent satellites is novel and forms part of the disclosed invention. Additional details of this aperture synthesis technique will be described below.

C-Band Satellite Communication System and Antenna

The C-Band satellite communication system of the disclosed invention only requires an antenna having an area equivalent to that of a three foot or less diameter parabolic dish to adequately receive the signal from existing C-Band satellites in their current configuration, yet stays within the FCC power limits of radiated power from the satellite that reaches the ground. To meet the power limitation of approximately 36 dB EIRP at C-Band frequencies (3.9-6.2 GHz) in a relatively small receiving antenna, the disclosed invention employs a combination the above video compression and spectral shaping techniques. By compressing the data, the required received power is reduced by a factor of ten. Thus, within the same power limitation on radiated power from the satellite of -152 dBW/m^2 in a 4 kHz bandwidth, an antenna with one tenth the area can be used.

The C-Band satellite communication system includes a small receiving antenna to receive conventional C-Band satellite transmissions. Due to the combined use of the above three features, however, the antenna of the disclosed invention can have an area on the order of that of a three foot diameter dish, which is much smaller than any C-Band satellite antenna known to be in use today for receiving television.

By reducing the antenna diameter, the beam width is normally increased. Reducing the diameter from 8 feet to 3 feet increases the beam width from 1.8° to 4.9°. The result is that the smaller antenna can normally no longer discriminate between adjacent C-Band satellites in their current orbital configuration.

The disclosed invention solves the beam width problem by designing the receiving antenna with nulls in its antenna pattern that correspond to those orbital locations in which potentially interfering satellites are located. The nulls are specific to C-Band frequencies and are located in orbit directions ± 2° to ± 4° from beam center, where adjacent satellites are located.

To create the desired nulls, the disclosed invention employs the above mentioned aperture synthesis technique, i.e., shaping the antenna not in a circle but in an irregular shape that puts nulls in its antenna pattern that correspond to precisely those orbit locations where interfering signals are expected to originate. Nulls in the specific locations unique to the satellite spacing at C-Band address the specific problem of the C-Band television industry in a way that allows a breakthrough in service offerings. Nevertheless, the disclosed invention is not limited to C-Band implementations, but serves to significantly reduce the antenna size for any satellite frequency and satellite spacing.

The third component of the disclosed invention that allows a rapid implementation of DTH service to small antennas is the deliberate choice of the spectrally inefficient modulation technique discussed above. The disclosed invention uses an SFSK modulation scheme to keep the energy of the transponder spread smoothly over the bandwidth (about 30 MHz) of the satellite transponder. By using the SFSK modulation, the disclosed invention meets the FCC power flux density limitations and allows implementation of the disclosed invention in existing transponders without any increase in interference to other C-Band users. Thus, switching from current DTH service to the new service of the present invention can be easily accomplished. By choosing the optimum demodulation technique, the receivers of the disclosed invention are also less susceptible to interference from adjacent satellites, whether the other satellites carry normal C-Band traffic or the signal of the disclosed invention. By choosing the data rate and number of television channels to vary with each satellite's power level, the interference is equalized between satellites and the number of channels is optimized for a given antenna area on the ground.

Although the SFSK signals themselves have a coding gain, which is approximately equal to the transponder bandwidth divided by the data rate, by itself, SFSK gain is not sufficient to protect against adjacent satellites at ±2° spacing. It does, however, form part of the overall protection of the disclosed invention by reducing the requirements of the depth of the antenna sensitivity nulls and pointing accuracy required of the small antenna.

The combination of reduced data rate due to the video compression and the coding gain provided by the SFSK modulation reduces the depth of the antenna nulls required to achieve a significant reduction in antenna size. Nevertheless, sizable nulls are still required. At least 10 dB nulls in the direction of each interfering satellite are required to achieve the necessary isolation of the desired signal from the interfering satellite signals. The aperture synthesis technique described herein accomplishes the required 10 dB nulls in the direction of each interfering satellite.

The unique combination of digital television compression to reduce the overall power requirements, antenna beam synthesis to notch out satellite interference from adjacent satellites in the constellation, for example, from ± 2° and ±4° positions in synchronous orbit in the present C-Band configuration, and SFSK modulation to reduce intersystem interference, allows significant improvements in satellite television DTH service, especially in C-Band. The disclosed invention allows television programs to be offered to small-aperture user antennas without any change in the existing C-Band satellites. It allows the equivalent of direct broadcast satellite service (DBS) to be offered without any launch of new satellites. The current satellites can be switched from current service to the system of the disclosed invention one transponder at a time, as C-Band DTH users develop without interrupting existing service. This smooth transition without requiring any new satellite launches provides a major economic advantage to the system of the disclosed invention. In fact, the cost and delay inherent in any satellite launch forecloses implementing many other DBS system designs. By permitting a quick transition from previous service to the service of the disclosed invention, without the huge cost of a satellite launch, the system of the disclosed invention can be rapidly implemented in the marketplace. Furthermore, the C-Band system of the disclosed invention maintains a permanent advantage of reduced rain loss, giving a tenfold reduction in satellite transponder power required and a continuous major cost advantage to the C-Band system of the disclosed invention in competition with Ku-Band DBS existing service.

The combination of these three techniques allows a C-Band antenna design having an area equivalent to that of a three foot diameter dish, as compared to existing C-Band antennas which vary between 8 and 10 feet in diameter. Due to the small size, the C-Band system of the disclosed invention does not require an installation professional to install the antenna or a concrete pad to support it. Finally, the aesthetics of the antenna are improved by allowing the user to locate the antenna in a convenient location wherever the antenna has an unobstructed line of sight to the satellite, such as the roof, a window, etc. Thus, the disclosed invention reduces initial investment costs for consumers and improves aesthetics, which permits a DTH system that can effectively compete with existing CATV systems in urban areas yet also accommodates users in rural areas where CATV is not feasible. Thus, the disclosed system combines the advantages of DTH systems, i.e., accessibility to rural users, with the advantages of CATV systems, relatively low cost installation for urban areas. In fact, the system of the disclosed invention costs less to install than a CATV system, if the satellites are already in existence.

Ku-Band Satellite Communication System and Antenna

The same general technique is possible for a Ku-Band satellite communication system and antenna. Generally, the problem is similar to the problem in the C-Band system. Ku-Band frequencies (15.35-17.25 GHz) are used for direct broadcast television. Due to the frequencies involved some differences exist in the orbital spacing of the satellites and the allowable FCC power limitations. The FCC power limits are higher at Ku-Band than C-Band, however, losses due to rain absorption and thermal noise are higher at Ku-Band frequencies. Therefore, to use a smaller antenna at Ku-Band than what is in current use (about two to five feet in diameter) normally would require higher radiated power. This is not possible due to the FCC limitations. However, equivalent size savings on Ku-Band antennas are possible with the combination of the video compression, spectral shaping and antenna design techniques discussed above, when tailored for the Ku-Band environment.

Essentially for the same constellation of satellites discussed above, spaced at ±2° intervals, the antenna dimensions reduce by the ratio of the respective wavelengths. The gaps in the antenna remain in the same proportional locations as for the C-Band system. For example, to modify the antenna from C-Band to Ku-Band, the scaling ratio becomes:

$$\frac{\lambda_C}{\lambda_{Ku}} = \frac{f_{Ku}}{f_C} = \frac{16.3\,GHz}{5.05\,GHz} = 3.23 \qquad (3)$$

Thus, the Ku-Band antenna can be scaled down directly from the C-Band version by a factor of about 3.23. Since the C-Band antenna has an area approximately equivalent to a three foot diameter dish, the K-Band antenna has an area approximately equivalent to a one foot diameter dish or less, with gaps in the same proportions as the C-Band system. For example, let "x" denote the position from the center of the antenna where the gaps are located, then x/3.23 denotes the placement of the gaps in the Ku-Band version of the antenna of the disclosed invention. Current Ku-Band parabolic dish antennas are about 3 feet in diameter, hence the disclosed invention permits a significant reduction in antennas for this frequency band as well.

L-, S- and Ka-Band Communication Systems and Antennas

The same technique is also possible to reduce the receiving antenna size for other frequency bands, such as L-Band (0.390-1.550 GHz), S-Band (1.55-5.20 GHz) and Ka-Band (33-36 GHz). To reduce the antenna size requires a reduction in the amount of data per unit bandwidth, which is solved by data compression techniques. Where television signals are involved, video data compression techniques permit a significant reduction in data, approximately 90% (i.e., the compressed digital signals are about 1/10 the information rate of the uncompressed signals). This by itself is not sufficient to significantly decrease the antenna size with existing satellite configurations. When combined with a modulation technique that reduces the power flux density, provides some gain, and allows an increase in the transmission power, the receiving antenna can be significantly reduced in size.

The receiving antenna must also be designed according to the disclosed invention to permit the receiving antenna to operate in the transmission footprint of multiple satellites in the constellation, yet still discriminate between the satellite of interest and those adjacent to the satellite of interest. The same technique described herein will work in the S-, L- and Ka-bands. The only special considerations for operating at S-, L- and Ka- bands are the shaping of the antenna to achieve the required nulls in the antenna patterns, the specific spacing between satellites in orbit and the satellite power required including the effect of compression and also rain absorption. A unique combination of beam shape, antenna shape, modulation shape and the number of television channels per transponder is appropriate for each band following the procedure illustrated by the basic C-Band system description.

As before, for the same constellation of satellites discussed above, spaced at ±2° intervals, the antenna dimensions are reduced by the ratio of the respective wavelengths. The gaps in the antenna remain in the same proportional locations as for the C-Band system. For example, to modify the antenna from C-Band to L-Band, the scaling ratio becomes:

$$\frac{\lambda_C}{\lambda_L} = \frac{f_L}{f_C} = \frac{0.97\,GHz}{5.05\,GHz} = \frac{1}{5.2} \qquad (4)$$

Thus, the L-Band antenna can be scaled up directly from the C-Band version by a factor of about 5.2. Since the C-Band antenna has an area approximately equivalent to a three foot diameter dish, the L-Band antenna has an area approximately equivalent to a 15.6 foot diameter dish, with gaps in the same proportions as the C-Band system. For example, let "x" denote the position from the center of the antenna where the gaps are located, then 5.2x denotes the placement of the gaps in the L-Band version of the antenna of the present invention. Existing L-Band parabolic dish antennas are approximately three times in diameter, hence the disclosed invention permits a significant reduction in the receiving antenna for L-Band implementations as well.

For example, to modify the antenna from C-Band to S-Band, the scaling ratio becomes:

$$\frac{\lambda_C}{\lambda_S} = \frac{f_S}{f_C} = \frac{3.375\,GHz}{5.05\,GHz} = \frac{1}{1.5} \qquad (5)$$

Thus, the S-Band antenna can be scaled up directly from the C-Band version by a factor of about 1.5. As a result, since the C-Band antenna has an area approximately equivalent to a three foot diameter dish, the S-Band antenna has an area approximately equivalent to a 4.5 foot diameter dish, with gaps in the same proportions as the C-Band system. For example, let "x" denote the position from the center of the antenna where the gaps are located, then 1.5x denotes the placement of the gaps in the S-Band version of the antenna of the present invention. Existing S-Band parabolic dish antennas are approximately three times in diameter, hence the disclosed invention permits a significant reduction in the receiving antenna for S-Band implementations as well.

For example, to modify the antenna from C-Band to Ka-Band, the scaling ratio becomes:

$$\frac{\lambda_C}{\lambda_{Ka}} = \frac{f_{Ka}}{f_C} = \frac{34.5\,GHz}{5.05\,GHz} = 6.8 \qquad (6)$$

Thus, the Ka-Band antenna can be scaled down directly from the C-Band version by a factor of about 6.8. As a result, since the C-Band antenna has an area approximately equivalent to a three foot diameter dish, the Ka-Band antenna has an area approximately equivalent to a 0.44 foot diameter dish, with gaps in the same proportions as the C-Band system. For example, let "x" denote the position from the center of the antenna where the gaps are located, then x/6.8 denotes the placement of the gaps in the Ka-Band version of the antenna of the disclosed invention. Existing Ka-Band parabolic dish antennas are approximately three times in diameter, hence the disclosed invention permits a significant reduction in the receiving antenna for Ka-Band implementations as well.

In using the design technique of the invention disclosed in U.S. Patent Application No. 08/259,980, if the area is more or less than that desired, if for example, due to satellite power limitations or rain losses, then the gaps in the East-West dimensions can be kept as before, but the widths in the North-South dimensions can be scaled to achieve the desired area. For example, the North-South dimensions could be doubled to achieve twice the area without changing the locations of the antenna nulls in the East-West orbit positions.

Description of the Antenna for the C-Band System

FIG 1 depicts an embodiment of the receiving antenna of the invention disclosed in U.S. Patent Application No. 08/259,980 for use in the C-Band satellite communication system. As evident in FIG 1, the antenna comprises a main reflector 1, and two side reflectors 2 and 3, as well as an antenna feed 4. The main reflector 1 and both side reflectors 2 and 3 have parabolic surfaces. The radius of the embodiment of the antenna shown in FIG 1 from the feed 4 to the main reflector surface 1 is F_1, which is about 20.0 inches. The radius from the feed 4 to the side reflectors is F_2, which is about 28.8 inches. The antenna has a fresnel step equal to $F_1 - F_2$, i.e., about 8.8 inches. The length of the antenna from the outside edge of one side reflector 2 to the other 3 is 57.5 inches. The width or horizontal dimension of the side reflectors, 2 and 3, is 19.2 inches, and the width or horizontal dimension of the main reflector is 13.3 inches. The vertical dimension of the main reflector is about 10.55 inches, while the vertical dimension of the side reflectors is about 5.48 inches.

The antenna of the disclosed invention uses a spill over baffle to prevent thermal energy from the ground behind the antenna from reaching the feedhorn. As seen in FIG 1, the spill over baffle 6 is located in the outer edge of the outer reflectors.

The aperture synthesis for the C-Band antenna of the disclosed invention is designed to provide normal gain for a satellite at one position in the synchronous orbit and provide low-gain nulls for satellites at ± 2°, ± 4°, ± 6° and ± 8° away in synchronous orbit. The depth of the nulls can vary, but must be at least 10 dB to prevent interference. Thus, the antenna is designed to receive from only one of the satellites in a constellation at a time, while simultaneously inhibiting reception from the remaining satellites in the constellation, especially those directly adjacent to the targeted satellite. The reason for inhibiting reception from these satellites is that they are the single largest source of potential interference since they are transmitting at nearly the same radio frequencies, but the signals contain different programs than the signal from the targeted satellite. These interfering signals will seriously distort the received signal, and prevent proper decoding unless they are suppressed by the antenna pattern.

In the C-Band version of the disclosed invention, the actual position of the required nulls are in fact a little wider than the ±2° spacing because the antenna on the surface of the earth is closer to the constellation of satellites than the earth's center, as evident in FIG 2. FIG 2 depicts the typical antenna pattern of a three foot receiving antenna receiving signals from the current constellation of television broadcast satellites operating in the C-Band range. The arrows in the figure represent interfering satellites 11, 13, 15, 19, 21 and 23. The target satellite 17 is centered at the maximum gain of the receiving antenna.

The 3 db cutoff frequency of the receiving antenna is about 5.68° from center. A diameter of 36" equals about 91 centimeters. The wavelength λ of a representative signal in the C-Band, i.e., about 4 GHz, is determined by:

$$\lambda = \frac{C}{f} = \frac{3 \times 10^{8}\ meters/\mathrm{sec}}{4 \times 10^{9}\ \mathrm{sec}^{-1}} = 0.075\ meters \qquad (7)$$

The three-dB cutoff angle, α, is determined typically by the following formula. Thus, at 4 GHz α becomes:

$$\alpha \approx \frac{69\,\lambda}{D} = \frac{69 \times 0.075\ meters}{0.91\ meters} = 5.69^{\circ} \qquad (8)$$

The difference from the ±2° spacing varies from a maximum of ±2.35°, when the satellites are above the same longitude as the ground antenna, to ±2.11°

when the satellites are 60° east or west of that position. These variances can be accounted for by designing the gaps to be at the mean of these values, and providing sufficient depth in the null to account for when the receiving antenna is at the extremes.

In analyzing the antenna performance, it is most useful to treat the problem as a ray tracing problem. The antenna gain can be found by tracing rays from the antenna feed horn 4, or central power collector, to the surface of the reflector 1 and from there out to the far distance, or "infinity" in a particular direction. When the direction lies along the main axis of a parabolic antenna, the distance traveled by all rays from feed-horn to reflector to the distant point is the same, as shown in FIG 3. All increments of power traveling those paths will arrive with the same delay, since $l_w=l_o=l_e$. Therefore, the field in that direction will receive all increments of energy in phase with each other reinforcing each other for maximum gain.

Conversely, for a direction some degrees off the main axis (as shown in FIG 4), the energy reflected from different parts of the parabolic reflector 1 travel paths of different lengths. Energy from the reflector side l_w that is closer to the direction of the main axis (the near side) travels a shorter path than energy from the center of the reflector, l_o, hence $l_w<l_o<l_e$. As a result, the energy from the near side arrives earlier in phase than the energy from the center; and the energy from the far side arrives later in phase than the energy from the center. When energy from all of the reflector is combined at the distance, some increments add and some subtract from the whole. In aggregate, the sum totals less than the sum of the energy in the main axis of the antenna. When the distance difference from the center of reflector to the edge of reflector reaches one half of the radio frequency wavelength, λ, the energy from the edges directly subtracts from the energy from the center. The diameter of the antenna at this point is given by the relationship:

$$\frac{D}{2}\sin\phi_{1/2} = \frac{\lambda}{2} \quad where \quad \lambda = \frac{C}{f} \tag{9}$$

With a normal reflector feed design, at an angle twice $\phi_{1/2}$, energy from the edges is delayed by one whole wave length and is back in phase with energy from the center. This will cause the energy at $2x\phi_{1/2}$ to be reinforced again causing a minor peak in the antenna pattern.

The values where the actual nulls in the patterns and the subpeaks occur depend precisely on the shape of the feed horn pattern illuminating the reflector, the shape of the reflector and the blockage of any energy by structures, such as the feed horn and its supports. For a typical antenna design, the diameter required to reduce the gain to reasonable protection levels for ±2° satellite spacing at C-Band, f=4 GHz., λ=0.075 m, is about 8.5 feet. In the antenna of the disclosed invention, even though digital television compression and spectral shaping would allow an antenna as small as 3 feet in diameter, the interference of satellites at ± 2.24°, ± 4.48°, etc. preclude the standard small dish.

The disclosed invention solves this problem by using sections of parabolas with areas blocked out to control the phases of energy reaching the directions at ± 2.24°, ± 4.48°, etc. in such a way as to cause nulls, or large attenuations, at precisely these positions in the satellite orbit. The basic parabola is pointed at the desired satellite of interest (referred to as the targeted satellite) and all field components in directions towards the interfering satellites add up with different phase angles to cause the precise cancellations.

FIG 1 depicts one embodiment of the disclosed invention. The top view of the antenna shows that three sections of the normal parabolic surface have been retained, a central section and two side sections in the east-west directions parallel with the earth's equator. The section widths in the north-south direction can be adjusted to increase or decrease the amount of energy in any east-west location. For example, the outer contour of the antenna may have an irregular shape rather than a smooth curve to add and subtract area in the antenna to add or subtract the energy reaching the antenna as desired. The north-south dimension can be reduced to zero, i.e., by placing a gap between sections, to accomplish the desired nulls, or it can be widened to increase energy in desired directions.

FIG 6 shows the projection of energy arriving at the satellite 2.24° from the central satellite. The reference phase is that of energy arriving from the center of the reflecting surface. What is plotted is the cosine of the phase angle between this central energy and energy from off axis positions. As energy comes from further away from the center, the projection decreases, goes through zero and becomes negative. A gap 7 exists between the main reflector 1 and the two side reflectors, 2 and 3.

FIG 7 shows the same projection but this time for energy arriving at ± 4.48° from the central satellite. The same behavior is seen but now the zero appears twice as close to the center.

FIG 8 shows the same for satellites at ± 6.72°. Similar plots are found at ± 8.96°, etc.

To find the field strength at 2.24°, the shaded area of FIG 6 would be integrated over the reflecting surface. More precisely, the physical area of each reflector element should be further weighted by the gain of the feed horn antenna in the direction of the reflector elements.

In the example of FIG 6, the reflecting area and gap are selected to illustrate the principle. The gap size and location have been selected to cause energy from the positive central section to cancel with negative phases for the two edge sections. This causes a null at ± 2.24° off the axis from the central satellite.

In this particular example, the energy at ± 4.48°, shown in FIG 7, will not precisely cancel as can be found by integrating FIG 7 over the aperture and gap. However, to improve on cancellation at ± 4.48°, area can be added or subtracted at any point by increasing or decreasing the north-south width of the main reflector. In FIGs 6-8 this direction is into the paper. If area is added in the region where the ±2.24° curve, FIG 6, goes through zero, then there will be no change to the ±2.24° cancellation while the ±4.48° cancellation will be improved.

In a similar way, areas of the antennas where the ±4.48° curve goes through zero can be increased or decreased in width to refine the nulls at ±2.24° and ±6.72° without affecting the null at ±4.48°. Since only four sets of nulls need to be canceled before the pattern will remain below the required level, the problem is underconstrained, i.e., there are many different fine adjustments of the widths in the North-South dimension that can be made to cancel the signals in the ±2.24°, ±4.48°, ±6.72° and ±8.90°locations.

Because the antenna's gain beyond 8° is systematically below the required levels, the cancellation at ± 2.24°, ± 4.48°, ± 6.72° and ± 8.96° need only be balanced using the procedure of the disclosed invention. There are many more degrees of freedom in the design than necessary to create the required eight nulls in the east-west pattern of the antenna. A number of combinations of feed horn gain, gap sizes and north-south width choices exist that create the required notches. The embodiment illustrated in the drawings utilizes apertures that are rectangular in outline as projected in the direction of the satellite, a central area that is blocked by the feedhorn, and avoidance of gaps between the main and side reflectors as seen from the feed point.

FIG 5 illustrates the antenna pattern resulting from the antenna depicted in FIG 1. The numbers in the top view in FIG 5 represent the field strength of the feed horn on the antenna surface. The gap and north-south dimensions have been chosen to accomplish the desired cancellation. As shown in FIG 5, the 0's in the central section represent feed horn blockage; B represents the width of the outer reflector; B_c represents the width of the inner reflector; and W is the width of the antenna. Only one half of the antenna is shown. The numbers in FIG 5 depict the signal strength on the antenna at the particular coordinates. For example, 25 mV is the electric field strength of the antenna at 28 inches in the East-West direction and about 5 inches in the North-South Direction. The dots represent places where the signal strength is effectively zero. FIG 9 shows the gain of the antenna at the different angles showing the desired nulls in the desired positions. Thus, FIG 9 depicts the off-axis performance of the antenna.

FIG 1 also shows a second innovation of the antenna of the disclosed invention. The full gap between center and side sections allows the use of what is termed a Fresnel lens improvement. As long as the antenna reflecting surface is parabolic, the gain will be achieved in the principal direction. One feed can be used with different parabolic surfaces. Near the center, parabolas with short focal length are used, near the edge parabolic surfaces with large focal lengths are used. As long as each parabola differs from a reference focal length by integer multiples of 1/2 wavelength, the energy in the principal beam will all add in phase as if they were from a single parabolic surface. This allows approximately the same performance with an antenna that is physically thinner. The steps between parabolas are made abruptly, causing a bit of loss from fringing effects, but also giving some mechanical strength improvements in some designs. In this embodiment, the fresnel step is F_1 - F_2.

In the antenna of the disclosed invention, an advantageous embodiment is made by having the central section constructed with a shorter-focal-length parabola than the end sections. This embodiment has three advantages. First, it makes the structure smaller and stronger. Second, it improves the antenna efficiency by having the gap required for cancellation take up the area that would be in shadow as seen by the feed horn. Third, it makes the feed horn pattern easier to realize, since the desired central reflector is smaller in the north-south dimension than the edge reflectors. The ideal feed would normally have a dumbbell pattern, pinched in the middle and wider at the sides. Moving the central reflector near to the feed increases the ideal beam width of the feed in the center section, making it more nearly oval and realizable with a more standard feed horn.

The feed horn shown in the embodiment of FIG 1 is 2.25 inches in the East-West dimension and 8 inches in the North-South dimension. The feed horn pattern that results from this configuration is elliptical, which is wide in the East-West dimension and narrow in the North-South dimension. One other possible design for the feed horn would be to use a conventional rectangular pyramidal horn. A feed horn design with an elliptical mouth rather than a rectangular mouth would also suffice.

The Fresnel step between center and outside parts of the antenna thus increases the efficiency of the feed horn without compromising the actual area of the antenna of the performance at the desired null points. While the present embodiment depicts a particular fresnel step in which the focal length increases from the main reflector to the side reflectors, a number of different step options are possible in alternative embodiments.

Thus, the antenna of the disclosed invention is designed to shape the feed pattern and the reflector area to create nulls at the interfering satellite points. The technique to do this has been described above. While one realization has been illustrated and described in detail, many variations are possible.

One specific addition to the general approach is to use different focal-length parabolas on physically separated sections. This configuration can improve the feed efficiency as well as the mechanical design.

FIG 12 depicts a cross-section of one half of the antenna. FL=focal length. The bottom part of FIG 12 indicates the aperture distribution of the antenna of the disclosed invention. E(n) represents the total signal strength of the antenna at a given East-West location for the entire North-South dimension. Thus, E(n) is the integral of the signal strength at a particular East-West location as the integral runs along a strip from one edge to the other in the North-South dimension. At 4 GHz, the center reflector is raised 3 wavelengths with respect to the outer reflector.

The physical design of the antenna will be described next. The antenna consists of four parts: a central section 1, two wings 2 and 3, and a frame 8, as depicted in FIG 13. FIG 13 is a general view of the antenna. The shape of the frame, which is rendered schematically, may take any suitable form.

The central dish is a 13.28" x 13.28" square segment of a paraboloid of focal length 19.95 inches (H-H'-J'-J in FIG 13), centrally situated around the vertex of a paraboloid.

The height of the surface above the vertex at radial distance r in inches measured in the level plane is expressible as $r^2/79.8$. For example, at the center of each square side the height is 6.64 x 6.64/79.8 = 0.553 inches above the vertex. At the corners the height is 1.106 inches.

Table I gives the surface heights above a grid of points spaced one inch in both directions in the level plane. Only one quarter of the square is tabulated. The remaining parts of the square can be determined from the symmetry of the antenna.

FIGs 14a-14c are graphs of the cross-section of the dish along F'-E-F (or G'-E-G) in FIG 13. The drawing in the upper left depicts a side view of the antenna; the drawing in the lower left depicts a plan view of the antenna; and the drawing in the lower right depicts a right view of the antenna. The graph depicts the height of the center section of the antenna above E, which is the center point of the center section.

edge	0	1	2	3	4	5	6	6.64
0	E 0	1	5	11	20	31	45	F 55
1	1	3	6	13	21	33	46	56
2	5	6	10	16	25	36	50	60
3	11	13	16	23	31	44	56	66
4	20	21	25	31	48	51	65	75
5	31	33	36	43	51	63	76	87
6	45	46	50	56	65	76	90	100
6.64	55 G'	56	60	66	75	87	100	110 H'

Table I. Surface heights for central dish

Each wing is a rectangular segment of a paraboloid of focal length 28.8 inches (C-D-D'-C) in FIG 13. The inner edge CC' is situated at a distance 14.0 inches from the axis of the central dish, measured in the level plane. With respect to the (x,y,z) coordinate system indicated in FIGs 14a-c, the positions of representative points are as given in Table II.

The height of the surface of the wings at radial distance r in inches measured in the level plane from the axis of the central square dish, is expressible as $r^2/115.2$. For example, at point A in FIG 14b, which is 14.01 inches from E, measured horizontally, the height is 14.01 x 14.01/115.2 = 1.704 inches (compare line 1 of Table II).

Point	x	y	z
A	14.01	0	1.7
B	28.76	0	7.18
C	14.01	9.59	2.5
D	28.76	9.59	7.98
E	0	0	8.95
F	6.64	0	9.4
G	0	6.64	9.94
H	6.64	6.64	9.95

Table II. Coordinates of representative points

Table III gives the depth of the wing relative to the plane passing through the corners C, D, D′, and C'. Only one half of the rectangle is tabulated.

Edge	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	15.74	
A 85	97	108	117	124	129	133	135	136	135	132	128	122	115	106	95	86	B C/L 0
85	97	107	116	123	128	132	134	135	134	131	127	121	114	105	94	85	1
82	94	104	113	120	126	129	132	132	131	129	124	118	111	102	91	82	2
77	89	100	108	115	121	125	127	128	127	124	120	114	106	97	88	77	3
71	83	93	102	109	114	118	121	121	120	118	113	107	100	91	88	71	4
62	74	85	93	101	106	110	112	113	112	109	105	99	92	82	72	63	5
52	64	75	83	90	96	100	102	103	102	99	95	89	81	72	61	52	6
48	52	62	71	78	84	88	90	91	30	27	83	77	69	60	49	40	7
26	38	49	57	64	70	74	76	77	76	73	69	63	55	46	35	27	8
10	22	33	42	49	54	58	60	61	68	57	53	47	40	31	20	11	9
0 C'	12	23	31	39	44	48	50	51	50	47	43	37	29	20	10	0 D'	9.53

Table III. Wing surface heights in hundredths of an inch.

The surface of the model is electrically conducting and generally smooth. The present embodiment does not differ from the tabulated values by more than 0.15 in r.m.s.

A frame of electrically nonconducting material holds the dish and two wings in position relative to each other as in Table III, within an accuracy of ±0.05 inches. The frame should be rigid, robust, and portable. It is possible to affix other elements, especially a feed support bracket or brackets and electrical cables.

While the above description referred to placing narrow nulls in specific locations, the disclosed invention would also operate if the nulls were replaced by broad attenuation at these same locations. All that is required is to adequately reduce the signal strength below the threshold at which interfering signals would impair reception. While this threshold varies with each implementation, attenuating the signals by 10 dB should be sufficient.

Furthermore, while the above description created these nulls by placing gaps between the main reflector and the two side reflectors, any effective gap would also suffice. An effective gap is defined herein as a place where the area in the antenna is reduced significantly but not to zero. Thus, a "neck" could exist between the main reflector and each of the two side reflectors, but not a gap. Such a design may have particular advantageous properties, such as ease of fabrication.

In addition, the above antenna design described a symmetrical antenna. An asymmetrical antenna would also suffice, as long as the signal strength of the interfering signals was reduced below the above threshold.

Finally, the antenna of the disclosed invention would work in applications where the underlying data was something other than television. The antenna will apply to any system in which the user desires to reduce the size of the antenna to a point at which its beam width no longer covers only one satellite, but rather is now receiving interfering signals from satellites near the satellite of interest as well as the desired signal.

Finally, while electronic phase cancellation techniques are known, they are very expensive due to the complex equipment involved. The disclosed invention performs its aperture synthesis without the benefit of complex electronics.

Description of the Spectral Shaping Technique

The invention disclosed in U.S. Patent Application No. 08/259,980 uses a bandwidth spreading technique to reduce the power density below the FCC thresholds for each of the systems. This technique also reduces the effect of interfering signals on the received signal.

The disclosed invention uses a Shaped Frequency Shift Key (SFSK) modulation scheme to spread the energy of the transponder smoothly over the bandwidth of the satellite transponder, which in the case of the C-Band system spreads the signal over the 30 MHz of the current C-Band satellite transponder. Frequency Shift Keying (FSK) is a commonly known modulation technique. Minimal Shift Keying (MSK) is an FSK signal shifted in such a way as to minimize the frequency spreading. By "SFSK" we mean any of many shapes of frequency versus time patterns that will occupy the wider bandwidth without losing power efficiency. By spreading the bandwidth from 5 MHz to 30 MHz using the SFSK modulation technique, the power density is reduced below the FCC limitation.

The SFSK signals themselves have a "coding gain" approximately equal to the transponder bandwidth divided by the data rate, a protection achieved for any power efficient modulation scheme. This amounts to a protection factor of between three and ten depending on the number of television signals of the disclosed invention in one satellite transponder.

Three different SFSK modulation shapes are available, depending on whether the transponder of the disclosed invention uses one, two or three channels, which depends on the power from the transponder. A transponder radiating its signal at 30-31 dB EIRP transmits one television channel using a particular SFSK modulation; a transponder radiating its signal at 31-33 dB EIRP transmits two channels using a different modulation; and a transponder radiating its signal at 35 dB or greater EIRP can transmit three channels using a third modulation.

One possible embodiment of this aspect of the disclosed invention uses Manchester Encoding for the three channel implementation. For example, if the information data rate is 5 megabits per second (MBPS) per channel, the total information data rate becomes 15 MBPS. By coding the information bits into two transmitted bits using Manchester Encoding, the 15 MBPS signal will be transformed into a 30 MBPS signal, which easily occupies the 30 MHz bandwidth of the transponder.

For the two channel implementation, i.e., a 10 MBPS signal must be transformed into a 30 MBPS signal. This can be accomplished by using three data bits per information bit, i.e., triple redundancy. As before, the resulting 30 MBPS signal can easily occupy the 30 MHz bandwidth available on the satellite transponder.

For the one channel implementation, i.e., a 5 MBPS signal would be transformed into a 30 MBPS signal, which can be accomplished using a 6 data bits per information bit. The modulation desired can be accomplished using digital bit expansion as above followed by spectral shaping, or alternatively, by any of a number of shaping filters on the transmitter and matched filters on the receiver.

In addition to modifying the spectrum to occupy the full bandwidth available as described above, the disclosed invention modifies the number of channels depending upon the transponder EIRP available on the chosen satellite. For example, if the satellite transponder has only 31 dB EIRP available, then the system of the disclosed invention will send only one channel via that satellite. Additional protection is therefore automatically provided by the resulting coding gain, e.g., 30 MHz/5 MBPS, which is a factor of six. For example, if the satellite transponder has only 33 dB EIRP available, then the system of the disclosed invention will send two channels via that satellite. Additional protection is therefore automatically provided by the resulting coding gain, e.g., 30 MHz/10 MBPS, which is a factor of three. Finally, if the satellite transponder has 35 dB

EIRP or more available, then the system of the disclosed invention will send three channels via that satellite. No additional protection is necessary.

The adjustment of number of channels for a given satellite EIRP equalizes the interference performance of the system. Normally the satellite radiating a stronger signal, such as 35 dB EIRP, would provide three times the interference to a weaker signal at 30 dB, for example, from an adjacent satellite. As a result, the signal from the higher power satellite would require one-third the coding gain to protect it from the signal from the weaker satellite. Using only one television channel on the satellite radiating the weaker signal automatically provides the required improvement in protection for the weaker satellite. The choice of SFSK modulation type and channels per transponder is deliberately made to equalize the protection needed by the antenna pattern and the television demodulator no matter which of the satellites is being received in a constellation of satellites of unequal power.

Description of the Video Compression Technique

The disclosed invention incorporates existing data compression techniques. All that is required is a data compression algorithm that reduces the data by a factor of about ten. The embodiment of the disclosed invention uses a commercially available product from Scientific Atlanta to provide the required video data compression. This same product will suffice in all embodiments, i.e., the C-, S-, L-, Ku- and Ka-Band systems.

Description of the C-Band and Ku-Band Communication Systems

The basic embodiment of a system for transmitting the signal of the disclosed invention is depicted in FIG 10. The general block diagram will not vary when the system is changed to a different band, such as Ku-, Ka-, L- or S-Band. The only change occurs in the satellite transmitter 117 and the antenna 118, which now radiate the signal to the satellite at a different RF frequency.

The system operates as follows. FIG 10 depicts the ground transmitter of the disclosed invention. The video signal 110 is converted by an analog to digital converter 111 into a digital signal 112. The digital signal 112 is converted into a compressed digital signal 114 by the data compressor 113, which has been described above. The compressed digital signal 114 is modulated by the SFSK modulator 115 into a wideband analog SFSK uplink signal 116, using the modulation technique described above. The ground station transmitter 117 transmits this wideband analog SFSK signal using the ground station antenna 118, which radiates the RF signal 119 to the satellite. A satellite transponder 130, which is depicted in FIG 15, receives the incoming wideband analog SFSK signal 119 with antenna 131, passes it to receiver 132 which outputs the SFSK signal to frequency translator 133, which shifts the signal in frequency to a desired downlink frequency, such as a C-Band frequency, for example, which is different than the uplink frequency to prevent interference. The transmitter 134 outputs the wideband analog SFSK signal at that frequency and radiates the RF signal 136 towards the earth.

The RF signal constitutes a broadband signal centered at the carrier frequency of the satellite transponder, which in the C-Band system is approximately 4 GHz. The details of the link are set forth below.

FIG 11 depicts the ground portion of an embodiment of the disclosed invention. The antenna 120, which is of the type described above, receives the RF signal 136 transmitted from the satellite, along with interfering signals and noise. The antenna 120 outputs the received signal to an SFSK demodulator 121, which converts the received signal into a compressed digital signal 122 that approximates the compressed digital signal 114 from FIG 10. The SFSK demodulator outputs this compressed digital signal 122 to a data restorer or decompressor 123, which converts the compressed digital signal 122 into a digital signal that approximates the digital signal 112 from FIG 10. The data decompressor passes the digital signal 124 to a digital to analog converter 125, which converts the digital signal 124 to a video signal 126 that resembles the video signal 110 in FIG 10. Thus, the system communicates the video signal from the ground transmitter, shown in FIG 10, via a satellite transponder 130 to a user on the ground, who is able to employ an antenna with a receiving area equivalent to a dish having a three foot or less diameter, yet which satellite does not violate FCC regulations regarding transmitted power. Additional control and data transmission signals of lower overall data rate can be added at transmitter and receiver to manage billing and to deliver additional information to the user. Typically, the data compression and expansion include encryption techniques to protect proprietary materials. Furthermore, error correction and detection techniques may also be employed without corrupting the disclosed invention. The exact RF signal levels will be set forth below in the link equations.

The physical equations that define the relations between the transmitted satellite radio power and the size of the dish antennas are usually called the "link equations." In normal algebraic form they define the ratio of signal power received, P_r, to noise power received, P_n. The signal power received is determined by:

$$P_r = \frac{P_s G_s \eta A_r}{4 \pi R^2 A_b} \qquad (10)$$

where:

P_s = transmitted satellite power;

G_s = satellite antenna gain, the ability to focus the power on just the country being served;

ηA_r = the effective area of the receive antenna;

π = 3.1415927;

R = the distance from satellites to ground station, typically;

A_b = absorption factor due to rain and atmosphere.

The noise power received by the antenna is a function of temperature, and can be determined by:

$$P_n = k T_r B \qquad (11)$$

where:

k = 1.38 X 10-23, Boltzman's constant, a physical constant relating temperature of "black body" radiation;

T_r = effective radiation temperature of the receive station;

B = the bandwidth of the signal being received.

television in its various forms has a bandwidth that varies from 4.7 MHz for normal broadcast, to 30 MHz for satellite FM television, and from to 1 MHz to 8 MHz for compressed digital television.

The required performance is given by a minimum ratio (C/N) of received signal power P_r, which is determined from equation (10), to noise P_n, which is determined from equation (11). Thus, C/N becomes:

$$\frac{C}{N} = \frac{P_r}{P_n} = \frac{P_s G_s \eta A_r}{4\pi R^2 k T_r B A_b} \tag{12}$$

The required ratio (C/N) is determined by the required television transmission mode and varies from normal broadcast television, to Satellite FM television relay, and to the new digital television broadcast. Since the choice of transmission mode defines the bandwidth B and the required (C/N) at the same time, these two parameters are usually grouped together:

$$B\frac{C}{N} \tag{13}$$

The required satellite power (P_s) can be defined in terms of the other system choices by factoring of terms in equation (12).

$$P_s = \frac{\frac{C}{N} B (4\pi R^2) A_b T_r k}{G_s \eta A_r} \tag{14}$$

Equation (14) contains the information relevant to the comparison of Satellite TV services offered in the two frequency bands, C-Band and Ku-Band. The satellite power, P_s, is the primary space segment cost factor because the scarce solar cell power has to be divided among the powers required for each transponder, which determines how much each channel shares in the total satellite cost.

The two factors shown in equation (13) are determined solely by the choice of the TV modulation type to be used. The most relevant types are normal broadcast TV, Satellite FM-TV, the type currently used in C-Band Satellites, and compressed video. Table IV below lists the values for these three types of TV transmission.

TV Type	B	C/N	B•C/N
Broadcast TV	4.6 MHz	3000	1380×10^7
Satellite FM-TV	30 MHz	8	24×10^7
Compressed Video	5 MHz	4	2.0×10^7

Table IV. Modulation Parameters, B•C/N

Normal broadcast television requires over 20 times greater power from the satellite than FM television. Even though some information agencies have proposed transmitting directly from satellites to home television sets, the need for twenty times the satellite power has proven to be impractical.

The standard satellite FM television has been used for years as the basic-technique for both C-Band and Ku-Band satellites. Until just recently it was the best available to minimize required satellite power. The advent of the new digital signal processors (DSPs) has made compressed digital television practical. The compression reduces the B•C/N parameter by a factor of 10, which means that without any other change in the system the satellite power or the antenna area can be reduced by a factor of 10 simply by changing to the new television system. The performance improvement applies to both Ku- and C-Bands, as well as S-, L- and Ka-Bands.

The range to the geosynchronous satellites, R, is typically 40,000 Km. As a result, the factor $4\pi R^2$ becomes 2×10^{16} m^2, which is the same for both Ku-Band and C-Band.

The gain of the satellite, G_s, depends entirely on the area of the country to be covered. For normal coverage of the United States, a gain of approximately 25 dB, which is 300 in algebraic terms, is achievable. The satellite's gain is limited to 300 by the area of geographic coverage, whether C-Band or Ku-Band is used. To achieve this gain Ku-band must use a smaller satellite antenna, which results in some weight savings on the satellites, but not enough to much affect the satellite cost.

The total power in the satellites is also proportional to the effective area of the receive station antenna, ηA_r. For an antenna with an efficiency of 60%, the effective area is

$$\eta A_r = \frac{0.60 \pi d^2}{4} \qquad (15)$$

A directly related parameter is the antenna gain given by the equation:

$$G = \frac{4\pi\eta A_r}{\lambda^2} \qquad (16)$$

Table V gives the effective areas of several possible embodiment of antennas. The effective area is also independent of Ku-band or C-band frequency choice. The related gain is dependent on the frequency band chosen.

Antenna Diameter (Inches)	(meters)	60% Area	Gain at 4 GHz
18	0.46	0.1 m^2	23.5 dB
36	0.92	0.4 m^2	29.5 dB
72	1.8	1.6 m^2	35.5 dB

Table V. Effective Antenna Areas at 60% Efficiency

The remaining two parameters, T_r and A_b, are strongly dependent on the choice of C-Band or Ku-Band frequency. C-Band frequencies are little effected by rain while Ku-Band frequencies, which are a lot closer to the rain absorption frequencies, are much worse. A lot of statistical data has been gathered to determine the margins required, the values used below are mid-way between extremes. The rain margin at C-Band frequencies is typically 0.8 dB, or 1.20 in algebraic terms. The rain margin for the same rates of rainfall at Ku-Band are 8 dB, which is a factor of 6.3 in algebraic terms. These absorption factors multiply the required satellite power directly. A C-Band transmission requires 1.2 times the power to overcome rain loss, while a Ku-Band transmission requires 6.3 times to overcome rain loss.

An added effect comes from noise radiation due to the rain itself. Without the absorption the receiver has a temperature at C-Band that is a little better than that available at Ku-Band. C-Band typically is 50°K while Ku-Band is more typically 80°K. However, both noise temperatures are affected by added radiation from rain. The relationship is given by:

$$T_r' = T_r + 290° \frac{(A_b - 1)}{A_b} \quad (17)$$

T_r is the clear-sky receiver temperature. 50°K for C-Band or 80°K for Ku-Band. A_b is the absorption factor in algebraic terms for the different frequencies, 1.2 for C-Band, 6.3 for Ku-Band. The result is

$$C\text{-}Band\text{: } T_r' = 50° + 290° \frac{(1.2 - 1)}{1.2} = 98° K \quad (18)$$

$$Ku\text{-}Band\text{: } T_r' = 80° + 290° \frac{(6.3 - 1)}{6.3} = 324° K \quad (19)$$

These values can then be used in equation (14) to determine the satellite power P_s required for a given choice of modulation antenna size and frequency band. For the first example we will choose Satellite FM TV transmitting to a 6-foot receiver at C-Band.

C-Band FM TV 6-foot antenna:

$$P_s = \frac{(24\times10^7)\times(1.38\times10^{-23})\times(2\times10^{16})\times1.2\times98}{300\times1.6} = 16.2\ watts \qquad (20)$$

Ku-Band FM TV 6-foot antenna:

$$P_s = \frac{(24\times10^7)\times(1.38\times10^{-23})\times(2\times10^{16})\times6.3\times324}{300\times1.6} = 281\ watts \qquad (21)$$

The above shows that C-Band into a six-foot antenna requires 16 watts per transponder, while Ku-Band into the same size receiver requires 281 watts if rain margins are accounted for.

The power levels can be expressed in Effective Isotropic Radiated Power (EIRP) using the formula:

$$EIRP = 10\log_{10}(P_s \times G_s) \qquad (22)$$

For the U.S., coverage of G_s=300, the two cases become:

FM TV: C-Band: 6-foot receiver: EIRP = 36.8 dBW
FM TV: Ku-Band: 6-foot receiver: EIRP = 49.2 dBW

The dishes used in C-Band are larger typically than 6 feet if the weaker satellites are being received, eight, ten, and even fifteen feet are used on fringe areas where signals are weaker.

The early Ku-Band satellites for the U.S. used up to 300 watt Ku-Band transmitters, leading to high space segment cost and often short transmitter lifetime. In Europe, where each country is smaller, allowing larger Gs, tubes of 100 watts were used in Ku-Band. Some systems have used smaller Ku-Band antennas but then suffer signal loss when rain occurs.

Equation (22) can be used with any of the combinations of antennas and modulation types discussed above. In Table VI, the combinations have been given for the stated alternatives.

Band	Mod.	B•C/N	Ant.	ηA_r	T_r'	A_b	W	EIRP
C-Band	FM-TV	$24x10^7$	72"	1.6	98	1.2	16.2	36.8
		$24x10^7$	36"	0.4	98	1.2	64.8	42.8
		$24x10^7$	18"	0.1	98	1.2	259	48.9
Ku-Band	FM-TV	$24x10^7$	72"	1.6	324	6.3	281	49.2
		$24x10^7$	36"	0.4	324	6.3	1124	55.2
		$24x10^7$	18"	0.1	324	6.3	4500	61.3
C-Band	Dig.TV	$2.0x10^7$	72"	1.6	98	1.2	1.62	26.8
		$2.0x10^7$	36"	0.4	98	1.2	6.48	32.8
		$2.0x10^7$	18"	0.1	98	1.2	25.9	38.9
Ku-Band	Dig.TV	$2.0x10^7$	72"	1.6	324	6.3	28.1	39.2
		$2.0x10^7$	36"	0.4	324	6.3	112.4	45.2
		$2.0x10^7$	18"	0.1	324	6.3	450.0	51.3

Table VI. EIRP Modulation, Band & Antenna

The receivers available to C-Band and Ku-Band for compressed Video can be slightly better than the parameter B•C/N assumed above, resulting in the reception with one or two dB less EIRP than listed in Table VI. The improvement comes from error correcting demodulation allowing lower B•C/N and therefore lower B•C/N.

The best approach however would appear to be to use the 36" antenna area with about 31 dB EIRP for one compressed video channel. This allows all existing satellites to be used.

The parameter B•C/N will increase directly proportional to the number of channels if multiple channels are combined on the same transponder. Two channels double the data rate and the satellite power. Three channels triple the data rate and satellite power.

This embodiment of the disclosed invention uses the following design goals:

Compressed Video C-Band EIRP:

31 dBW 1 channel
34 dBW 2 channels
35.7 dBW 3 channels

The increased number of channels with satellite EIRP has the effect of equalizing performance for a given sized antenna that has different satellites in the interference nulls of the antenna. An antenna receiving a 31 dBW satellite on its main beam but with an interferer at 2° away in orbit with 35.7 dBW needs three times the protection than if the interferer were of equal, i.e., 31 dBW, EIRP. The modulation of the disclosed invention automatically compensates for this situation because if the central satellite has only one channel its coding gain, the protection given by the modulation, is three times better, as required.

Advantageous Embodiments

One advantageous embodiment of an antenna for receiving a signal transmitted from a constellation of satellites, which includes a central satellite and a plurality of satellites spaced at regular intervals from the central satellite includes two heavy attenuations matched to at least two pairs of satellites in the constellation that are immediately adjacent to the central satellite, wherein the two heavy attenuations prevent signals from the at least two pairs of adjacent satellites from interfering with a signal being transmitted from the central satellite.

Another advantageous embodiment of an antenna for receiving a signal from a central satellite in a constellation of satellites, which includes the central satellite and a plurality of satellites spaced at regular angular intervals from the central satellite relative to the antenna, comprises: a central reflector; a first side reflector; a second side reflector; a first effective gap between the central reflector and the first side reflector, the first effective gap having a significantly reduced area relative to an area of the central reflector and an area of the first side reflector; and a second effective gap between the central reflector and the second side reflector, the first effective gap having a significantly reduced area relative to the area of the central reflector and the area of the second side reflector, in which the first and second effective gaps create at least two nulls in received energy, which two nulls inhibit signals being transmitted from at least two pairs of satellites in the constellation that are immediately adjacent to the central satellite.

Another advantageous embodiment of an antenna for receiving a signal from a central satellite in a constellation of satellites, which includes the central satellite and a plurality of satellites spaced at regular angular intervals from the central satellite relative to the antenna comprises: a central reflector; a first side reflector; a second side reflector; a first effective gap between the central reflector and the first side reflector, the first effective gap having a significantly reduced area relative to an area of the central reflector and an area of the first side reflector; and a second effective gap between the central reflector and the second side reflector, the first effective gap having a significantly reduced area relative to the area of the central reflector and the area of the second side reflector, in which the first and second effective gaps create at least two regions of heavy attenuation in received energy, which two regions of heavy attenuation inhibit signals being transmitted from at least two pairs of satellites in the constellation that are immediately adjacent to the central satellite.

Another advantageous embodiment of the above antenna includes first and second side reflectors that are physically separate from the central reflector.

Another advantageous embodiment of an antenna for receiving a signal transmitted from a constellation of satellites, which includes a central satellite and a plurality of satellites spaced at regular angular intervals from the central satellite relative to the antenna comprises: a reflecting surface having an irregularly shaped contour that provides normal gain for a signal from the central satellite and low gain nulls for signals from the plurality of satellites, in which the low gain nulls prevent signals being transmitted from the plurality of satellites from interfering with a signal being transmitted from the central satellite.

An advantageous method for receiving a signal being transmitted from a constellation of satellites, which includes a central satellite and a plurality of satellites spaced at regular angular intervals from the central satellite relative to a receiving antenna, comprises the steps of: enhancing a signal being transmitted from the central satellite with a central reflector in the receiving antenna; inhibiting interfering signals being transmitted from the plurality of satellites by disposing a gap between a central reflector and each of two side reflectors in the receiving antenna; and selecting a width of the gap and widths of the central and two side reflectors so that energy from the interfering signals that impinges on the central reflector cancels out energy from the interfering signals that impinges on the two side reflectors.

Another advantageous method for receiving a signal being transmitted from a constellation of satellites, which includes at least a central satellite, a first adjacent satellite spaced from the central satellite by a first angular interval relative to a terrestrial receiving antenna, a second adjacent satellite spaced from the central satellite by a second angular interval that is twice the first angular interval, and a third adjacent satellite spaced from the central satellite by a third angular interval that is three times the first angular interval, comprises the steps of: enhancing a signal being transmitted from the central satellite with a central reflector in the receiving antenna; canceling interfering signals from the first, second and third adjacent satellites by: (i) placing a gap between the central reflector and each of two side reflectors in the receiving antenna; and (ii) selecting an east-west dimension of the main reflector relative to an east-west dimension of the side reflector such that energy of the interfering signals impinging upon the main reflector cancels with energy of the interfering signals impinging upon the side reflectors.

Another advantageous method for receiving a signal being transmitted simultaneously from a constellation of satellites, which includes at least a central satellite, a first adjacent satellite spaced from the central satellite by a first angular interval relative to a terrestrial receiving antenna, a second adjacent satellite spaced from the central satellite by a second angular interval that is twice the first angular interval, and a third adjacent satellite spaced from the central satellite by a third angular interval that is three times the first angular interval, comprises the steps of: enhancing a signal being transmitted from the central satellite with a central reflector in the receiving antenna; canceling a first interfering signal from the first adjacent satellite by: (i) placing a gap between the central reflector and each of two side reflectors in the receiving antenna; and (ii) selecting an east-west dimension of the main reflector relative to an east-west dimension of the side reflector such that energy of the first interfering signal impinging upon the main reflector cancels energy of the first interfering signal impinging upon the side reflectors; canceling a second interfering signal from the second adjacent satellite by: (i) selecting an area of the main reflector relative to an area of the side reflector such that energy of the second interfering signal impinging upon the main reflector cancels with energy of the second interfering signal impinging upon the side reflectors without changing the cancellation of the first interfering signal in the second step; and canceling a third interfering signal from the third adjacent satellite by selecting a north-south dimension of the side reflector such that the energy of the third interfering signal impinging upon the main reflector cancels with energy of the third interfering signal impinging upon the side reflectors without changing the cancellation of the second or first interfering signals in the second or third steps.

An advantageous embodiment of the previous method occurs when the third step of canceling further comprises the step of: (ii) controlling a gain of the feedhorn such that the energy of the second interfering signal impinging upon the main reflector cancels with the energy of the second interfering signal impinging upon the side reflectors.

An advantageous embodiment of one of the previous methods occurs when the second step of canceling further comprises the step of: (ii) controlling a gain of the feedhorn such that the energy of the second interfering signal impinging upon the main reflector cancels with the energy of the second interfering signal impinging upon the side reflectors.

An advantageous method for sending a quantity of data representing a video signal to a terrestrial antenna from a ground transmitter via a main satellite within a constellation of satellites, which includes at least two pairs of adjacent satellites that are adjacent to the main satellite and spaced at regular angular intervals from the main satellite relative to the terrestrial antenna, comprises the steps of: compressing the quantity of data to form a quantity of compressed data; modulating the quantity of compressed data into a broadband power efficient signal that spreads the quantity of compressed data across a wide bandwidth of the ground transmitter so that the broadband power efficient signal has 3 to 8 dB of coding gain; transmitting the broadband power efficient signal from the ground transmitter to the main satellite; retransmitting the broadband power efficient signal from the satellite; receiving the broadband power efficient signal with the terrestrial antenna; providing gain in the terrestrial antenna for the broadband power efficient signal being retransmitted from the main satellite; and inhibiting signals being transmitted from the at least two pairs of adjacent satellites that are independent of the signal being transmitted from the main satellite.

An advantageous embodiment of the previous method occurs when the seventh step of inhibiting further comprises providing a gap in the terrestrial antenna between a central reflector and two side reflectors, wherein a width of the gap and widths of the two side reflectors are matched to the regular angular intervals of the at least two pairs of adjacent satellites.

An advantageous method for sending a video signal to a terrestrial antenna from a ground transmitter via a constellation of satellites, which includes a central satellite and a plurality of satellites spaced at regular angular intervals from the central satellite relative to the terrestrial antenna, comprises the steps of: converting the video signal into a quantity of digital data; compressing the quantity of digital data to form a quantity of compressed digital data; modulating the quantity of compressed digital data into a broadband power efficient signal that spreads the quantity of compressed digital data across a bandwidth of the ground transmitter so that the broadband power efficient signal contains 3 to 8 dB of coding gain; transmitting the broadband power efficient signal from the ground transmitter to the main satellite; retransmitting the broadband power efficient signal from the main satellite; receiving the broadband power efficient signal with the terrestrial antenna; enhancing the broadband power efficient signal being transmitted from the central satellite with a central reflector in the terrestrial antenna; inhibiting interfering signals being transmitted from the plurality of satellites by disposing a gap between a central reflector and each of two side reflectors in the receiving antenna; and selecting a width of the gap and widths of the two side reflectors so that energy from the interfering signals that impinges on the central reflector cancels out energy from the interfering signals that impinges on the two side reflectors.

An advantageous method for sending a video signal to a terrestrial antenna from a ground transmitter via a constellation of satellites, which includes at least a central satellite, a first adjacent satellite spaced from the central satellite by a first angular interval relative to the terrestrial antenna, a second adjacent satellite spaced from the central satellite by a second angular interval that is twice the first angular interval, and a third adjacent satellite spaced from the central satellite by a third angular interval that is three times the first angular interval, comprises the steps of: converting the video signal into a quantity of digital data; compressing the quantity of digital data to form a quantity of compressed digital data; modulating the quantity of compressed digital data into a broadband power efficient signal that spreads the quantity of compressed digital data across a wide bandwidth of the ground transmitter so that the broadband power efficient signal contains 3 to 8 dB of coding gain; transmitting the broadband power efficient signal from the ground transmitter to the constellation of satellites; retransmitting the broadband power efficient signal from the constellation of satellite; receiving the broadband signal from the constellation of satellites with the terrestrial antenna; enhancing a broadband signal being transmitted from the central satellite with a central reflector in the terrestrial antenna; and canceling interfering signals from the first, second and third adjacent satellites by: (i) placing a gap between the central reflector and each of two side reflectors in the terrestrial antenna; and selecting an east-west dimension of the main reflector relative to an east-west dimension of the side reflector such that energy of the interfering signals impinging upon the main reflector cancels with energy of the interfering signals impinging upon the side reflectors.

An advantageous method for sending a video signal to a terrestrial antenna from a ground transmitter via a constellation of satellites, which includes at least a central satellite, a first adjacent satellite spaced from the central satellite by a first angular interval relative to the terrestrial antenna, a second adjacent satellite spaced from the central satellite by a second angular interval that is twice the first angular interval, and a third adjacent satellite spaced from the central satellite by a third angular interval that is three times the first angular interval, comprises the steps of: converting the video signal into a quantity of digital data; compressing the quantity of digital data to form a quantity of compressed digital data; modulating the quantity of compressed digital data into a broadband power efficient signal that spreads the quantity of compressed digital data across a wide bandwidth the ground transmitter so that the broadband power efficient signal contains 3 to 8 dB of coding gain; transmitting the broadband power efficient signal from the ground transmitter to the constellation of satellites; retransmitting the broadband power efficient signal from each of the satellites in the constellation of satellites; receiving the broadband power efficient signal with the terrestrial antenna; enhancing a main broadband power efficient signal being transmitted from the central satellite with a central reflector in the terrestrial antenna; canceling a first interfering signal from the first adjacent satellite by: placing a gap between the central reflector and each of two side reflectors in the terrestrial antenna; selecting an east-west dimension of the main reflector relative to an east-west dimension of the side reflector such that energy of the first interfering signal impinging upon the main reflector cancels energy of the first interfering signal impinging upon the side reflectors; and canceling a second interfering signal from the second adjacent satellite by: selecting an area of the main reflector relative to an area of the side reflector such that energy of the second interfering signal impinging upon the main reflector cancels with energy of the second interfering signal impinging upon the side reflectors without changing the cancellation of the first interfering signals in the eighth step; and canceling a third interfering signal from the third adjacent satellite by selecting a north-south dimension of the side reflector such that the energy of the third interfering signal impinging upon the main reflector cancels with energy of the third interfering signal impinging upon the side reflectors without changing the cancellation of the second or first interfering signals in the eighth or ninth steps.

An advantageous system for transmitting a video signal from a ground transmitter via a main satellite within a constellation of satellites to a terrestrial antenna, comprises: a ground transmitter comprising: (i) an analog to digital converter converting the video signal to a digital signal; (ii) a data compressor being coupled to the analog to digital converter and compressing the digital signal to form a compressed digital signal; (iii) a wideband modulator being coupled to the data compressor and modulating the compressed digital signal into a wideband analog shaped frequency shift keyed signal that contains 3 to 8 dB of coding gain; (iv) a satellite transmitter being coupled to the wideband modulator and outputting a wideband RF signal; and (v) a satellite antenna radiating the wideband RF signal to the main satellite at a power level such that when the wideband RF signal is retransmitted by the main satellite and reaches the earth's surface the wideband RD signal is at a power level that is below FCC limitations on satellite transmissions at ground level; a terrestrial antenna having a diameter such that a beam width of the terrestrial antenna encompasses more satellites in the constellation of satellites than the main satellite, receiving the wideband RF signal and outputting a received signal; a wideband demodulator being coupled to the terrestrial antenna and demodulating the received signal into a received compressed digital signal; a data decompressor being coupled to the wideband demodulator and converting the received compressed digital signal into a received digital signal; and a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a received video signal.

An advantageous embodiment of the previous system occurs when the terrestrial antenna further comprises: a central reflector; a first side reflector; a second side reflector; a first gap between the central reflector and the first side reflector; and a second gap between the central reflector and the second side reflector, wherein the first and second gaps create at least two nulls in received energy, which two nulls inhibit signals being transmitted from the at least two pairs of adjacent satellites in the constellation.

An advantageous embodiment of the previous system occurs when the central reflector has a first parabolic reflecting surface, and the first and second side reflectors have a second parabolic reflecting surface.

An advantageous embodiment of the previous system occurs when the terrestrial antenna further comprises a fresnel step between the central reflector and the first and second side reflector.

An advantageous embodiment of the previous system occurs when a first parabola defining the first parabolic reflecting surface has a first focal length that is shorter than a second focal length of a second parabola defining the second parabolic reflecting surface.

An advantageous embodiment of the previous system occurs when the terrestrial antenna further comprises a feed horn, wherein the first and second gaps lie in an area obstructed from receiving signals from the central satellite by the feed horn.

An advantageous embodiment of the previous system occurs when a width of the central reflector is smaller in a north-south or vertical dimension than the first and second edge reflectors.

An advantageous embodiment of the previous system occurs when the first and second side sections are physically separate from the main section.

An advantageous receiver for receiving a video signal being broadcast via satellite to a terrestrial antenna as a wideband power efficient signal, comprises: a wideband demodulator being coupled to the terrestrial antenna and demodulating a received wideband power efficient signal being output from the terrestrial antenna, the received wideband power efficient signal containing 3 to 8 dB of coding gain, and the wideband demodulator converting the received wideband power efficient signal into a received compressed digital signal; a data decompressor being coupled to the wideband demodulator and decompressing the received compressed digital signal into a received digital signal; and a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a signal resembling the video signal.

A ground station for receiving a broadband power efficient RF signal being broadcast via a constellation of satellites to a terrestrial user, comprises: a terrestrial antenna receiving the broadband RF signal being broadcast from the constellation of satellites, outputting a received wideband power efficient signal, and having a diameter such that a beamwidth of the terrestrial antenna encompasses a target satellite in the constellation and at least the two pairs of satellites adjacent to the target satellite in the constellation; a wideband demodulator being coupled to the terrestrial antenna and demodulating the received wideband power efficient signal being output from the terrestrial antenna into a received compressed digital signal; a data decompressor being coupled to the wideband demodulator and decompressing the received compressed digital signal into a received digital signal; and a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a signal resembling the video signal being broadcast from the satellite.

A ground station for receiving a broadband power efficient RF signal being broadcast via a constellation of satellites to a terrestrial user, comprises: a terrestrial antenna receiving the broadband power efficient RF signal being broadcast from the constellation of satellites, outputting a received shaped frequency shift keyed signal, and having a diameter such that a beamwidth of the terrestrial antenna encompasses a target satellite in the constellation and at least the two pairs of satellites adjacent to the target satellite in the constellation; a shaped frequency shift keyed demodulator being coupled to the terrestrial antenna and demodulating a received shaped frequency shift keyed signal being output from the terrestrial antenna into a received compressed digital signal, wherein the received shaped frequency shift keyed signal contains 3 to 8 dB of coding gain; a data decompressor being coupled to the shaped frequency shift keyed demodulator and decompressing the received compressed digital signal into a received digital signal; and a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a signal resembling the video signal being broadcast from the satellite.

A ground station for receiving a television signal being broadcast as a wideband power efficient RF signal from a main satellite within a constellation of satellites, which includes at least two pairs of adjacent satellites adjacent to the main satellite and spaced at regular angular intervals from the main satellite relative to the ground station, the ground station comprises: a terrestrial antenna receiving the wideband power efficient RF signal, outputting a received signal, and having a diameter such that a beamwidth of the terrestrial antenna encompasses the main satellite and the at least the two pairs of adjacent satellites; a wideband demodulator being coupled to the terrestrial antenna and demodulating the received signal into a received compressed digital signal, wherein the received signal contains 3 to 8 dB of coding gain; a data decompressor being coupled to the wideband demodulator and converting the received compressed digital signal into a received digital signal; and a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a received television signal.

An advantageous embodiment of the previous ground station occurs when the terrestrial antenna further comprises: a central reflector; a first side reflector; a second side reflector; a first gap between the central reflector and the first side reflector; and a second gap between the central reflector and the second side reflector, wherein the first and second gaps create at least two nulls in received energy, which two nulls inhibit signals being broadcast from the at least two pairs of adjacent satellites.

An advantageous embodiment of the previous ground station occurs when the central reflector has a first parabolic reflecting surface, and the first and second side reflectors have a second parabolic reflecting surface.

An advantageous embodiment of the previous ground station occurs when the terrestrial antenna further comprises a fresnel step between the central reflector and the first and second side reflector.

An advantageous embodiment of the previous ground station occurs when a first parabola defining the first parabolic reflecting surface has a first focal length that is shorter than a second focal length of a second parabola defining the second parabolic reflecting surface.

An advantageous embodiment of the previous ground station occurs when a first parabola defining the first parabolic reflecting surface has a first focal length that is different than a second focal length of a second parabola defining the second parabolic reflecting surface.

An advantageous embodiment of the previous ground station occurs when the terrestrial antenna further comprises a feed horn, wherein the first and second gaps lie in an area obstructed from receiving signals from the central satellite by the feed horn.

An advantageous embodiment of the previous ground station occurs when a width of the central reflector is smaller in a north-south or vertical dimension than the first and second edge reflectors.

An advantageous embodiment of the previous ground station occurs when the first and second side sections are physically separate from the main section.

A ground station for receiving a video signal being broadcast as a wideband power efficient RF signal to a terrestrial user via a main satellite within a constellation of satellites, which includes at least two pairs of satellites adjacent to the main satellite and spaced at regular angular intervals relative to the terrestrial user, comprises: a terrestrial antenna receiving the wideband power efficient RF signal and outputting a received signal, and including an irregularly shaped contour that provides normal gain for a signal from the main satellite and low gain nulls for signals from the at least two pairs of satellites, wherein the low gain nulls prevent signals from the at least two pairs of satellites from interfering with a signal being transmitted from the main satellite; a shaped frequency shift keyed demodulator being coupled to the terrestrial antenna and demodulating the received signal into a received compressed digital signal; a data decompressor being coupled to the shaped frequency shift keyed demodulator and converting the received compressed digital signal into a received digital signal; and a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a received video signal available to the user.

A satellite within a constellation of satellites for retransmitting a signal to a terrestrial antenna, which has a diameter such that a beamwidth of the terrestrial antenna encompasses the satellite as well as other satellites within the constellation of satellites, comprises: a satellite receiver receiving a shaped frequency shift keyed signal being transmitted from a ground transmitter, which shaped frequency shift keyed signal contains 3 to 8 dB of coding gain; a satellite transmitter being coupled to the satellite receiver and retransmitting the shaped frequency shift keyed signal; and a satellite antenna radiating a wideband RF signal at a power level such that when the wideband RF signal reaches the earth's surface the wideband RF signal is below FCC limitations on radiated satellite power at ground level.

A geosynchronous satellite within a constellation of geosynchronous satellites for transmitting a C-Band signal to a terrestrial antenna, which has a diameter such that a beamwidth of the terrestrial antenna encompasses the geosynchronous satellite as well as other geosynchronous satellites within the constellation of satellites that are also transmitting C-Band signals, the satellite comprises: a satellite receiver receiving a wideband power efficient RF signal from a ground transmitter, which wideband power efficient RF signal contains 3 to 8 dB of coding gain; a satellite transmitter being coupled to the satellite receiver and outputting the wideband power efficient RF signal at a C-Band frequency; and a satellite antenna radiating the wideband power efficient RF signal at a power level equal to or less than 36 db EIRP.

A geosynchronous satellite within a constellation of geosynchronous satellites for transmitting a Ku-Band signal to a terrestrial antenna, which has a diameter such that a beamwidth of the terrestrial antenna encompasses the geosynchronous satellite as well as other geosynchronous satellites within the constellation of satellites that are also transmitting Ku-Band signals, the satellite comprises: a satellite receiver receiving a wideband power efficient RF signal from a ground transmitter, wherein the wideband power efficient RF signal contains 3 to 8 dB of coding gain; a satellite transmitter being coupled to the satellite receiver and outputting the wideband power efficient RF signal at a Ku-Band frequency; and a satellite antenna radiating the wideband power efficient RF signal at a power level equal to or less than 48 db EIRP.

An apparatus for transmitting a television signal to a satellite within a constellation of satellites, for broadcast back to earth to a terrestrial antenna, the apparatus comprises: an analog to digital converter converting the television signal to a digital television signal; a data compressor being coupled to the analog to digital converter and compressing the digital television signal to a compressed digital signal; a modulator modulating the compressed digital signal into a wideband power efficient signal that contains 3 to 8 dB of coding gain; an RF transmitter being coupled to the modulator and transmitting the wideband power efficient signal to a satellite at an RF power level such that when the wideband power efficient signal is retransmitted from the satellite and reaches earth the wideband power efficient signal lies within FCC limitations on satellite transmissions at ground level.

An advantageous embodiment of the previous apparatus occurs when the RF transmitter transmits the wideband power efficient signal to a geosynchronous satellite at a power level such that the geosynchronous satellite retransmits the wideband power efficient signal at a power level equal to or less than 36 dB EIRP and at a C-Band frequency.

An advantageous embodiment of the previous apparatus occurs when the RF transmitter transmits the wideband power efficient signal to a geosynchronous satellite at a power level such that the geosynchronous satellite retransmits the wideband power efficient signal at a power level equal to or less than 48 dB EIRP and at a Ku-Band frequency.

Relationship to the Present Invention

The reduction in surface area of the ground antenna for a small reduction in the number of available television channels clearly outweighs any reduction in the possible number of television channels. In fact, the digital television system described herein, and in U.S. Patent Application No. 08/259,980, provides more digital television channels than current analog television systems. For example, with digital television 8-12 channels per transponder can be accommodated with the existing TVRO dishes, and 3-4 channels per transponder can be accommodated using the small antenna. This results in an increase in the number of available channels from 432 to something on the order of 1296-1728 (3 to 4 x 18 x 24) channels. The maximum possible number of channels would be about 3456-5184 (8 to 12 x 28 x 24) channels. Therefore, viewers will be presented with an increase in the number of available channels while simultaneously being presented with a reduction in antenna size. Thus, the cost for this reduction in antenna size of fewer possible channels will never actually be felt by viewers.

While the modulation and compression techniques of the invention described herein, and in U.S. Patent Application 08/259,980, are tailored for the small receiving antenna described above, the resulting signals when broadcast by existing C-Band satellites will be easily received by larger, more sensitive antennas, particularly the existing 3 meter TVRO parabolic dish antennas. These antennas are not confronted with receiving interfering signals from adjacent satellites, since they have a more directional receiving pattern that only encompasses one of the C-Band satellites at a time. These larger antennas will simply have more signal-to-noise ratio (SNR) available for margin than the small antennas for which the system is designed. Therefore, the present invention provides an adapter module for converting the digital television signals into TV ready signals and for switching between analog and digital television so that both types of television signals can be received. The result is that a smooth transition from analog C-band television to digital C-band television is possible, without requiring users to dismantle their current systems.

The invention described in U.S. Patent Application No. 08/259,980 provides a unique format for transmitting digital television signals, which can be received either by the small antennas described above or the existing TVRO dishes. The format of the digital TV broadcast RF signal D transmitted from existing C-Band satellites is a minimal shift keyed (MSK) signal, also known as shaped frequency shift keyed (SFSK) signal, centered at a carrier frequency f_c and having a bandwidth of 32 MHz. The carrier frequencies lie between 3.75 GHz and 4.25 GHz. Each C-Band satellite contains multiple transponders; some have as many as 24 transponders (12 on each of 2 polarizations), hence each transponder transmits on a different carrier frequency to prevent interfering with adjacent transponders on the satellite. Each transponder transmits its MSK signal at a unique carrier frequency and one of 2 polarizations using a bandwidth of up to 36 MHz, which does not overlap with the other transponders on the C-Band satellite. The data rate of each signal lies below 36 megabits per second (Mb/s). Consequently, the signal from each transponder carries between 2-12 compressed digital television time domain statistically multiplexed (TDM) channels. The digital television signals are compressed using known video compression techniques, such as MPEG-1 or MPEG-2. The lowest number of channels is suited for signals being transmitted from the lowest power transponder of the C-Band constellation to the new satellite receiving antenna described above and in U.S. Patent Application No. 08/259,980, the description of which is hereby incorporated by reference, while the largest number is suited for signals being transmitted by the highest power transponder to existing large TVRO dish antennas.

FIG 16 depicts one embodiment of the present invention, which includes an outdoor unit 2 and an indoor unit 4. The outdoor unit consists of all existing equipment, i.e., an existing TVRO satellite antenna 1, a steering control 6, a polarization select 3, a low noise amplifier (LNA) 5, a block converter 9 and a control separator 7.

Two different RF signals from the same satellite impinge upon the parabolic dish, one that has one type of polarization and the other than has a type of polarization that is orthogonal to the first. For example, if the satellite transmits circularly polarized signals, then the RF signals are either left-hand circularly (LHC) polarized or right-hand circularly (RHC) polarized. If the satellite transmits linearly polarized signals, then the RF signals are either vertically polarized or horizontally polarized. Most U.S. C-Band analog TV signals are linearly polarized, while many overseas systems transmit signals using circular polarization. Either type can be easily accommodated in the present invention.

To receive the RF signal desired, a dipole antenna located in the feed horn is usually rotated between a position for receiving vertically polarized signals to a position for receiving horizontally polarized signals. The polarization select 3 receives the control signal E from the indoor unit 4, which causes the polarization select 3 to rotate the dipole antenna (not shown) to output the desired RF signal A. Alternatively, two dipoles could be mounted in the feed horn (not shown), and an electronic or mechanical switch can be used to select the desired polarization.

Due to the action of the polarization select 3, the polarized RF signal B is output to the LNA 5, which amplifies the RF signal B. The amplified RF signal C is then output to the block converter 9, which converts the RF transmitted signal to an intermediate frequency (IF). The block converter 9 then outputs the intermediate frequency signal D to the control separator 7, which separates the control signals (E and F) coming from the indoor unit 2 to the steering control 6 (control signal F) and the polarization select 3 (control signal E) from the IF signal D going to the indoor unit 4. The control separator 7 then outputs the intermediate frequency signal D to the coaxial cable 8. The coaxial cable 8 includes either additional coaxial cables or additional wire pairs to carry the control signals E and F.

ADAPTER MODULE

As shown in FIG 16, the indoor unit 4 includes an adapter module 11 according to the present invention, an existing controller 13, which includes the functions of channel select, polarization select and antenna steering, an existing decoder 17, an existing television 15 and a remote control 19 according to the present invention. The adapter module 11 receives the intermediate frequency signal D from the control separator 7. The adapter module 11 operates in one of two modes, an analog reception mode or a digital reception mode.

In the analog reception mode, the adapter module 11 passes the IF signal D through to the controller 13, which outputs the selected analog TV channel G to the decoder 17. The decoder 17 then performs all necessary functions to convert the received signal G to a television ready formatted signal H, e.g., the decoder 17 decrypts the signal G. The signal H is either at channel 3 or channel 4 in the VHF band, or at baseband. The decoder 17 then outputs the TV ready signal H to the adapter module 11, which in the analog reception mode merely passes the signal H through to the television 15 as signal I.

The remote control 19 of the present invention allows the user to select a television channel, or to otherwise control the existing analog TV system. When the user selects an analog channel in the analog reception mode, the remote control 19 outputs an infra-red (IR) (or equivalent) signal L, which gets simultaneously transmitted to the adapter module 11 and the controller 13. As shown in FIG 19, the IR receiver 31 (FIG 17) has an area 42 in the front face 41 of the adapter module 11 for receiving the IR signal L.

In the analog reception mode, the adapter module 11 ignores the IR signal L, and the controller 13 performs the desired function, e.g., tunes the channel select to the desired channel. Alternatively, the adapter module 11 could pass the IR signal L through to the controller 13, which simplifies the system operation for the user.

In addition, if the controller 13 needs to change the polarization or steer the antenna 1, the controller 13 outputs the control signals (E and F) to the adapter 11 module, which passes these signals (E and F) through to outdoor unit 2 via the coaxial cable 8.

In the digital reception mode, the adapter module 11 performs all of the functions to convert the IF signal D to a TV ready signal I and outputs this signal I to the television 15. The adapter module 11 also receives the IR signal L from the remote control 19, which signal L contains the user specified information. Based on this information, the adapter module 11 outputs the required control signals E and F to change the polarization or to steer the antenna 1.

FIG 17 depicts a block diagram of the functional modules inside the adapter module 11, and its connections to existing equipment. The adapter module 11 receives the IF signals D from the outdoor unit 2 via coaxial cable 8. The adapter module 11 also sends the steering control signal F and polarization select signal E to the outdoor unit 2 via the same coaxial cable 8, which may have either additional leads or coaxial cables inside it.

In the analog reception mode, the adapter receives the polarization select signal E and the steering control signal F from the existing controller 13, and passes these signals (E and F) to the outdoor unit 2 as described above. The adapter module 11 also passes the IF signal D through to the controller 13 in the analog reception mode. The existing decoder 17 then returns the TV ready signal H to the adapter module 11, which passes the TV ready signal H to the television 15 in the analog reception mode.

COAXIAL SWITCH

The adapter 11 has a switch setting 40 (FIG 18) that controls the operation of the adapter 11, i.e., the switch setting determines in which operational mode the adapter 11 is operating. The switch setting can be either a manual switch 40, as shown in FIG 18, or a user specified command transmitted to the adapter 11 via the IR remote control 19, which transmits IR signal L to the adapter 11. In fact, both switches can be employed to provide for complete flexibility to the user. The control unit then controls the position of the switch 21 via a control signal X.

Once the switch setting is established, a coaxial switch 21 determines the signal flow in and out of the adapter 11. The coaxial switch 21 is a known device, consequently its operation need not be described in detail here. In the analog reception mode, the coaxial switch 21 couples the IF signal D from the coaxial cable 8 through to the controller 13, and couples the control signals E and F from the controller 13 to the outdoor unit 2 via the coaxial cable 8. In the digital reception mode, the coaxial switch couples the IF signal D from the coaxial cable 8 to the tuneable demodulator 23, and couples the control signals E and F from the control unit 29 to the outdoor unit 2 via the coaxial cable 8.

A possible alternative to the first realization is a buffer amplifier from the first coaxial input allowing the incoming signal to go simultaneously to both analog and digital paths.

TUNEABLE DEMODULATOR

The adapter also contains a tuneable demodulator, which in the digital reception mode demodulates the digital IF signal D, at the carrier frequency specified by the control unit 29 via signal M. The digital TV broadcast RF signal D transmitted from the C-Band satellite is the MSK signal described above, centered at a carrier frequency f_c between 3.75 and 4.25 GHz, and having a bandwidth of 32 MHz. Each C-Band satellite contains multiple transponders, and some have as many as 12 transponders, hence each transponder transmits on a different carrier frequency and one of two polarizations to prevent interfering with adjacent transponders on the satellite. Each transponder transmits its MSK signal at a unique carrier frequency using a bandwidth of up to 32 MHz, which does not overlap with the other transponders on the C-Band satellite. The data rate of each signal lies below 36 megabits per second (Mb/s). Consequently, the signal from each transponder carries between 2-12 compressed digital television time domain modulated (TDM) channels.

The control signal M from the control unit 29 determines the carrier frequency for the tuneable demodulator 23. Demodulating MSK signals is known, hence no further description is necessary here. Once the carrier frequency is specified via control signal M, the tuneable demodulator outputs the bit sequence J modulated on the carrier using MSK modulation.

The bit sequence J modulated on the carrier for each transponder contains a data management channel (DMC), which specifies programming information regarding all of the offerings of the digital C-band television system. For example, the DMC contains information about each channel available, even channels that are being broadcast on other transponders or other satellites, or using other polarizations on the same transponder. The DMC also contains the programs being run currently on all channels, as well as all programs running for some time in the near future on all channels available to the user. The DMC is therefore identical on each transponder. Providing the DMC in each transponder permits the user to view listings of programs available without retuning the antenna or steering the antenna to a different satellite. In addition, the receiver can retune to a new channel without requiring viewer input.

The DMC includes the satellite on which each channel is being transmitted, the polarization being used, the transponder being used, and the time slot assignment, or bit frame assignment for each channel. This permits dynamic reassignment of these parameters by the system operator. For example, the system operator may wish to reassign a particular sports channel to a non-sports programming slot, whenever a sports talk show is being run rather than a sports event. Sports programs cannot be compressed as fully as movies due to the high motion content, consequently they consume more system resources than other channels. Therefore, in a digital system the system operator may wish to assign specific channels for sports programs to prevent overloading a satellite transponder. For example, one might assign a ratio of X sports channels for every Y channels ($X < Y$), to maintain a maximum bit rate per transponder. However, even channels dedicated to sports do not always carry programs that require the higher bit rate, i.e., sports events. Therefore, to maintain efficient use, one might wish to only assign channels actually carrying sports events to a higher bit rate channel assignment. In fact, this would permit broadcasters to opt to pay a premium for higher quality programming, such as the super bowl or a feature movie during ratings week. The DMC allows the system operator complete flexibility in accommodating these concerns on a dynamic basis so that the change is transparent to the viewer.

CHANNEL SELECT

The demodulated bit sequence J is then provided to a channel selector 25, which receives the channel specified by the user via the remote control 19. The channel selector outputs the user selected channel K to a decrypt and FEC unit 27, and outputs the DMC U to the control unit 29.

The channel selector demultiplexes the time-domain multiplexed compressed digital television channels into the individual television channels (2-12) and the DMC. The channels are multiplexed using statistical multiplexing, which is a known technique and need not be described here in detail.

DECRYPT & FEC

The user specified channel K output by the channel select 25 is provided to a decrypt and FEC unit 27, which performs the decryption and forward error correction (FEC) on the selected channel K. The decryption algorithm used can vary with the application, and is merely shown for completeness. Encrypting of the channels permits the system to lock out users who have not paid for a particular channel, yet to provide this channel to users who have paid for this particular channel. For example, a pay-per-view channel might be encrypted, and the decryption code sent to each subscriber who has paid. The FEC algorithm used will also vary with the application, but merely is shown for completeness. The minimum capability required is that a bit error rate of about 10^{-4} be correctable. This rate is determined by the acceptable bit error rate for the compressed television signals, which are sensitive to bit errors. Since every bit in a compressed television signal contains significant amounts of information, the quality of a compressed television signal falls sharply with increased bit error rates, compared to the analog channels. Bit error rates beyond this would result in system failure, i.e., the received signal could not be restored without significant artifacts appearing in the television signal. Algorithms exist that provide the necessary capability with reasonable overhead rates. The corresponding encoders and decoders are also available. The resulting corrected and decrypted but compressed digital television signal Q is then output by the decrypt and FEC unit 27 to a channel expander 20.

CHANNEL EXPANDER

The channel expander then performs the necessary decompression of the compressed digital television signal Q, using whatever algorithm was used to compress the signal. For example, if the television channel was compressed using either of the MPEG-1 or MPEG-2 compression techniques this channel expander 20 performs the inverse of that process. The decoders that perform this function for MPEG-1 or MPEG-2 are known, hence no details of how they function are required here. The channel expander 20 then outputs the restored digital television signal R.

PICTURE COMBINER

Since the system of the present invention is a digital television system, the system has the capability of overlaying text messages on the digital television for viewing by the user. One example would be text messages that appear at the bottom of the screen. Another example would be text messages that appear in a corner of the screen. To provide for this capability, the present invention includes a picture combiner 22 that combines text messages O output by the control unit 29 to a caption generator 24, which generates the overlay signal P. The overlay signal P is then combined in the picture combiner 22 with the digital television signal R to form a composite digital video signal S. Picture combiners and caption generators are known, hence no further details need be presented here. A possible efficiency option would be to incorporate the caption generator as an integral part of the channel expander software.

DIGITAL-TO-ANALOG CONVERTER

The present invention provides a standard digital-to-analog (D/A) converter 26 to convert the digital video signal S output by the picture combiner to an analog television ready signal T. Since the present invention employs a standard D/A converter, no further details need be provided here.

SPLITTER

The present invention employs a standard splitter 28 or buffer to provide either the TV ready signal H from the analog TV system or the TV ready signal T from the digital TV system to the television set 15. If the viewer selects the analog television reception mode, the adapter 11 will not provide a signal from the D/A converter 26, yet the decoder 17 will output signal H, which gets passed unchanged to the television 15. If the viewer selects the digital television reception mode, the adapter outputs the signal T from the D/A converter 26. Since the IF signal D is not being provided to the controller 13 in the digital reception mode, no signal H should be output from the decoder 17. If, however, this signal H contains undesirable noise due to the specific implementation of the existing analog equipment, a power plug 33 (FIG 19) can be provided on the adapter into which the power plug 33 for the existing analog equipment can be coupled. Thus, when the user selects the digital reception mode, the adapter module 11 could simply switch the power off to the analog television system, thereby preventing noise from appearing at the splitter 28, where the signal H would normally occur.

CONTROL UNIT

The present invention provides a remote control 19 that will permit the viewer to select analog or digital reception, as well as the channel desired. Since the viewer does not care to know the polarization or other details about each channel, once the viewer selects a channel for viewing, the control unit 29 outputs the desired polarization select signal E, the desired antenna steering signal F, the transponder select signal M and the channel select signal N. This capability permits the system broadcaster to change any of these details of the system, perhaps with the exception of the satellite, without notifying the viewer because the change will be transparent. Resteering the antenna will cause a loss of signal to appear on the screen until the antenna steers to the appropriate location, which can take a few seconds. Therefore, this change would appear to the viewer.

Sports programming often requires more bits per second than movies. Consequently, the system controller responsible for allocating channels to specific transponders can alter the mix of sports channels and other programs to maintain an efficient use of the bandwidth in a dynamic manner, all of which would be transparent to the viewer. In fact, the system could automatically determine that the current mix was inefficient, and modify the mix to an efficient mix, which would be transparent to the viewer. Since broadcasters pay per bit of information transmitted, any broadcast system must pay attention to the use of transmitted capacity so that capacity is not wasted in one transponder and limited in another. The present invention would permit such a dynamic modification of resource allocation, thereby maintaining system costs as low as possible.

This flexibility would allow a relatively quick conversion to digital TV. For example, the system could provide initially 6 to 10 digital channels per transponder to quickly convert cable and TVRO to digital, followed by a return to 3 to 4 channels to accommodate the small antennas and more satellites.

To provide for complete flexibility, the control unit 29 of the present invention includes a storage for storing default values for each digital television channel available. For example, the Table VII below provides an example of what might be stored in the control unit.

Program Channel Name*	Satellite	Polarization	Transponder Frequency	Bit Assignment
3 "Net 1"	Galaxy I	Vertical	3.7 GHz	1
4 "Net 2"	Galaxy I	Horizontal	3.718 GHz	2
5 "Net 3"	Galaxy II	Vertical	3.736 GHz	3
6 "Net 4"	Pioneer	Vertical	4.17 GHz	7

Table VII

*The terms "Net 1", "Net 2". . . are intended to designate the popular name of the network. In addition for each half hour for, say two weeks, a program description would be stored, e.g. "The Tale of Blue Beauty", "Mickey Goes to a Party", etc.

Initially, the control unit 29 is programmed with default values at which the system expects to assign each channel. When the adapter module 11 is first turned on, and tuned to a particular digital television channel, the control unit 29 outputs the parameters for that channel stored in its default library. Since the data management channel (DMC) is transmitted on each transponder, as soon as the adapter module 11 receives any signal it will receive the DMC. When the adapter module 11 receives the DMC, it updates its default library so that any changes are instantly accommodated. Therefore, when the viewer then retunes to a different channel, or begins channel surfing, the module will perform the necessary control to ensure that the viewer selected channel is output to the television 15, even if the channel has moved from its default value. At worst, the viewer might experience a brief delay when first turning on the adapter module while the adapter module updates the default values based on the current DMC being received. However, if the television is also turned on at the same time, by the time the television picture first appears the adapter module will have easily completed its modification of its default library.

The library stored in the adapter module contains the list of available channels and current and near-future programming. Since this data is stored, the user can recall this data at his convenience and manipulate it as well. For example, the user can create subsets of data representing only those channels he regularly views. This permits the user to quickly scan his favorite channels for programs of interest. The user could also create sets of data representing types of channels, e.g., sports, comedy, networks, etc., so that he can quickly scan the contents of these channels. Thus, the adapter module includes a user modifiable storage to enable the user to create these lists of channels, i.e., data subsets.

For example, a data rate of 100 kb/s could easily accommodate about 2 weeks of programming in 1/2 hour increments on all 400 or so channels. A two sentence description for each 1/2 hour slot could easily be included. Then, via remote control, the user could pull up the list of channels and select or deselect channels from the list and store the resulting list in memory by a name such as Bruce's list. Every time he wished to peruse the list, he could recall his saved list via remote control. The user could specify channels in order of most watched, category, alphabetical (i.e., popular name) or any order. The storage is provided in the control unit 29 in the form of RAM or user modifiable storage. The user's list would simply be output from the controller as text and overlayed on whatever is being viewed. This permits the user to quickly scan his choice without waiting for the information to scroll by, as in current systems.

DISPLAY

The present invention provides a display over which simple information such as which mode was operating and which channel is being output can be transmitted to the user. For example, in the analog mode, the channel being viewed is probably displayed on the current equipment. In the digital mode, this information must be provided to the user. In addition, the user might wish to know in which reception mode the equipment is currently set.

The present invention uses an LED 43 on the front face 41 of the adapter module 11 to display the fact that the system is operating in the digital TV mode. Another LED 44 displays the fact that the system is operating in the analog TV mode. A third LED displays system power. A numerical display 46 displays the digital TV channel being output by the adapter module. This display 46 contains at least three character positions to allow for up to 1000 channels. A fourth LED would permit 10000 channels to be displayed.

IR RECEIVER & TRANSMITTER

The present invention provides an IR remote control 19 for transmitting user selections to the system. An IR receiver 31 receives the IR signal L and converts this into an electrical signal W, which the IR receiver 31 outputs to the control unit 29. The IR transmitter can be used to send commands from the user to modify the channel, and to store/recall the new list in memory under a user specified name.

ADAPTER MODULE MECHANICAL DESIGN

The adapter module 11 is contained in a single housing. FIG 18 depicts the adapter module 11. The rear face of the adapter module 11 contains a coaxial input 34 for receiving the RF signal D from the outdoor unit 2. Another coaxial input 35 is provided for receiving the TV ready signal H from the decoder 17. A third coaxial input 37 is provided for receiving the control signals (E and F) from the controller 13.

A coaxial output is provided for outputting the control signals (E and F) to the outdoor unit 2. Two other coaxial outputs are provided, one coaxial output 38 for connecting to the television 15 and another for coupling the IF signal D to the controller 13.

A manual switch 40 on the top of the adapter module permits the user to manually switch from the analog TV mode to the digital TV mode, or vice versa. Cooling vents 32 are provided on the sides of the adapter module 11, only one side of which is depicted in FIG 18. A power plug 33 is provided to allow the user to plug in the existing analog converter so that power can be removed from that converter when necessary by the adapter module.

SYSTEM SIGNAL LIST

Each signal specified in the system is listed below in Table VIII, with its corresponding description.

SIGNAL	DESCRIPTION
A.	Output by existing TVRO antenna 1, which is either the analog TV RF signals or the new digital TV RF signals, which are being broadcast by all transponders on the C-Band satellite at which the TVRO antenna 1 is aimed. This signal contains both vertically and horizontally polarized RF signals.
B.	Output by existing polarization selector unit 3, which selects either the vertical or horizontal polarization signals being transmitted by all of the transponders on the C-Band satellite at which the TVRO antenna 1 is aimed.
C.	Amplified version of signal B output by the LNA 5.
D.	Signal C converted to an intermediate frequency from the RF signal.
E.	Polarization select control signal provided from existing system to select vertically or horizontally polarized signals. Also sent from the control unit 29 in the digital reception mode if necessary to select vertically or horizontally polarized signals.

F.	Steering control signal provided from existing system to steer the TVRO antenna 1 to a particular satellite. Also sent from the control unit 29 in the digital reception mode if necessary to steer the TVRO antenna 1 to a desired satellite.
G.	Signal from controller 13 to decoder 17 (not part of present invention).
H.	Analog TV Ready signal from decoder 17 intended for television 15.
I.	Analog or digital TV ready signal in NTSC format from splitter 28.
J.	Demodulated bit sequence from tuneable demodulator 23, which contains the entire bit sequence transmitted on one transponder of a particular satellite. This contains the DMC as well as 2-12 TDM compressed digital television channels statistically multiplexed together.
K.	Single compressed digital television channel output by the channel select 25.
L.	IR signal output by the remote control 19, which signal contains the user commands for the control unit 29.
M.	Control signal output by control unit 29 to select a particular transponder on the satellite at which the TVRO is aimed.
N.	Control signal output by control unit 29 to select a particular channel specified by the user via the remote control 19 available on the selected transponder.
O.	Text messages output by the control unit 29 for overlaying on the picture displayed on the television screen.

P.	Caption output by the caption generator 24 based on the text message O sent from the control unit 29.
Q.	Compressed, decrypted and error corrected digital television signal output by the decrypt and FEC unit 27.
R.	Restored digital television signal output by the channel expander 20.
S.	Digital television signal R combined with the caption P generated by the caption generator 24.
T.	TV ready signal output by the D/A converter in the digital reception mode.
U.	Data management channel (DMC) output by the channel select 25 to the control unit 29. The DMC contains programming information about all of the offerings of the digital television broadcast system. For example, the DMC contains information about each channel available, even channels that are being broadcast on other transponders or other satellites, or using other polarizations on the same transponder. The DMC also contains the programs being run currently on all channels, as well as all programs running for some time in the future on all channels available to the user. The DMC is identical on each transponder.
V.	Display signal sent from control unit 29 to the display 30.
W.	Electrical version of IR signal L sent to control unit 29 from the IR receiver 31 for the remote control 19.
X.	Control signal for switching the position of the coaxial switch.

Table VIII.

The present invention permits the broadcast operator to transition from analog C-Band service to digital service in a seamless manner without disrupting service to existing customers. First, the new digital service might employ eight to twelve digital television channels per transponder. This would permit existing TVRO dish owners to receive these broadcasts. To transition to the small antennas, the numbers of digital channels per transponder must be reduced. Therefore, additional transponders must be converted to digital television to accommodate the same number of channels. By simply updating the DMC, the adapter module can modify the channel parameters without user intervention. Consequently, this transition will have no impact on existing users while enabling new users with the small antennas to receive the new digital television broadcast. Thus, a rapid and seamless transition to digital TV is possible.

Initially, the digital television service might employ only a few transponders, with each transponder carrying 8-12 compressed digital television channels and the DMC. To transition to digital service to small antennas, the data rate per transponder must be reduced. To avoid dropping channels, some additional transponders must be converted to digital service, which means channels must be moved. Consequently, the user's receiver will track these changes based on the information in the DMC. To transition channels from one transponder to another, the receiver parameters for that channel must be updated simultaneously. The receiver would then retune to the appropriate channel. This permits a smooth transition from analog service to digital service for large TVRO antennas and then ultimately to small C-Band digital service.

The flexibility permitted by the present invention permits the broadcaster to modify the system resources based on current data being transmitted on a dynamic basis. For example, the broadcasting ground station can automatically monitor the bit rate of each transponder. As the transponder bit rate exceeds some threshold, the system could reassign channels among the available transponders to compensate, and then simply update the DMC to reflect this change. This would prevent one transponder from being overloaded. If no room was available on the transponders in use, the system operator could be notified so that additional transponders could be made available, or so that channels could be reassigned to a different satellite. Since the user becomes aware when channels move from one satellite to another due to the necessity of steering the antenna, this type of modification ought to be done as few times as possible. Nevertheless, the system has complete flexibility in assigning resources, even the ability to do so automatically.

WHAT IS CLAIMED IS:

1. An apparatus for converting an analog C-Band broadcast receiving system into a system for simultaneously receiving analog C-Band broadcast television signals and digital C-Band broadcast television signals, in which the analog C-Band broadcast receiving system includes an antenna, and an analog receiver for converting the received signal to a television ready signal selected by a user, the apparatus being coupled between the antenna and the analog receiver and between the analog receiver and a video device, said apparatus comprising:

a) a control unit having a digital operating mode and an analog operating mode, receiving a mode command from the user for switching the apparatus into either the analog operating mode for receiving the analog C-Band broadcast television signals or into the digital operating mode for receiving the digital C-Band broadcast television signals, receiving a digital channel selection command from the user indicating which digital television channel should be output in the digital operating mode, outputting a digital channel selection signal, and outputting a transponder selection signal;

b) a switch having an input being coupled to the antenna for receiving the signal, having a first output being coupled to said analog receiver, having a second output, having a control input being coupled to the control unit, whereby the control unit controls the switch via the control input so that the received signal is output to the second output in the digital operating mode and the received signal is output to the first output in the analog operating mode;

c) a demodulator being coupled to the second output of the switch, receiving the received signal in the digital operating mode, receiving the transponder selection signal from the control unit, and demodulating a bit sequence from the received signal at a carrier frequency specified by the transponder selection signal;

d) a channel selector receiving the bit sequence from the demodulator, receiving the digital channel selection signal from the control unit, and demultiplexing the bit sequence to form a selected compressed digital television signal;

e) a channel expander receiving the selected compressed digital television channel and decompressing the selected compressed digital television signal to form a selected digital television signal;

f) a digital-to-analog converter receiving the selected digital television signal and converting the selected digital television signal into an analog television-ready signal; and

g) an output coupler being coupled to the video device, receiving the analog television-ready signal from the digital-to analog converter in the digital operating mode, and receiving an additional analog television-ready signal from said analog receiver in the analog operating mode, and outputting the analog television-ready signal from the digital-to analog converter in the digital operating mode and outputting the additional analog television-ready signal in the analog operating mode.

2. The apparatus according to claim 1, wherein the control unit provides a polarization select signal to the antenna to change a polarization of the received signal received by the switch.

3. The apparatus according to claim 1, wherein the channel selector outputs a data management channel to the control unit, which data management channel contains information regarding programs available on all digital television channels on all satellites and transponders transmitting the digital C-Band broadcast television signals.

4. The apparatus according to claim 1, wherein several digital television signals are modulated on each transponder carrier signal using a minimum shift keying modulation technique and the demodulator demodulates the received signal using a minimum shift keying demodulation technique.

5. The apparatus according to claim 1, wherein a first plurality of digital television signals are transmitted by each transponder on each C-Band satellite using a first polarization and a second plurality of digital television signals are

transmitted by said each transponder on said each C-Band satellite using a second polarization, and the control unit transmits a polarization select signal to said antenna based on the digital channel selection command received from the user, which polarization select signal determines whether the received signal received by the switch contains the first plurality of digital television signals or the second plurality of digital television signals from the satellite at which the antenna is aimed and from the transponder specified by the control unit via the transponder select signal.

6. The apparatus according to claim 1, wherein a first RF signal containing a first plurality of digital television signals is transmitted by a first C-Band satellite and a second RF signal containing a second plurality of digital television signals is transmitted by a second C-Band satellite, and the control unit transmits a satellite steering control signal to said antenna based on the digital channel selection command received from the user, which satellite steering control signal determines whether the first RF signal or the second RF signal is received by the antenna.

7. The apparatus according to claim 5, wherein each C-Band satellite that is broadcasting digital television channels can dynamically reassign each digital television channels to any transponder on said each C-Band satellite, using any polarization and in any channel location within its multiplexing scheme, and said control unit correspondingly dynamically modifies the polarization selection signal, the digital channel selection signal and the transponder selection signal based on information contained in the data management channel to cause the channel selector unit to output the digital television channel specified by the user via the digital channel selection command.

8. The apparatus according to claim 7, wherein the control unit further comprises a storage unit storing a plurality of default values for each digital television channel available on all satellites and all transponders.

9. The apparatus according to claim 8, wherein the plurality of default values include a satellite indicator, a transponder indicator, a polarization indicator, and a bit frame assignment.

10. The apparatus according to claim 9, wherein the control unit regularly updates the plurality of default values based on information included in the data management channel.

11. The apparatus according to claim 1, wherein the control unit includes a storage unit that stores user specified data sets representing a user organized list of available channels.

12. The apparatus according to claim 1, further comprising a picture combiner having an input coupled to the control unit and an output coupled to the digital-to-analog converter, converting a text message signal output by the control unit into a text overlay signal, overlapping the text overlay signal on the selected digital television channel and outputting the text overlayed television signal to the digital-to-analog converter.

13. The apparatus according to claim 12, wherein the control unit further comprises a storage unit, the control unit outputs a master channel list of all available digital channels based on a user command to do so, which master list is overlayed on the selected digital television channel by the picture combiner, and the control unit creates a subset of the available digital channels based on a series of commands sent by the user and stores this list in the storage in a user named file.

14. The apparatus according to claim 13, wherein the control unit retrieves the user name file and outputs it to the picture combiner upon a command to do so from the user.

15. The apparatus according to claim 1, further comprising:

a) a caption generator being coupled to the control unit, wherein the caption generator receives a text message signal from the control unit and outputs a video text signal representing the text message; and

b) a picture combiner being coupled to the caption generator and the channel expander, receiving the video text signal from the caption generator, receiving the selected digital television signal from the channel expander, and combining the video text signal and the digital television channel into a combined text and video signal.

16. The apparatus according to claim 1, further comprising a display being coupled to the control unit for displaying the selected digital television channel number to a user.

17. A method for receiving both analog C-Band satellite broadcast television signals and digital C-Band satellite broadcast television signals using a single receiving antenna, a device for receiving the analog C-Band satellite broadcast television signals and an adapter module coupled to the receiving antenna and the device, in which a first plurality of digital television channels are multiplexed into a first bit sequence, a second plurality of digital television channels are multiplexed into a second bit sequence, the first bit sequence is modulated on a first carrier signal and transmitted from a first transponder on a particular C-Band satellite using a first polarization, the second bit sequence is modulated on the first carrier signal and transmitted from a first transponder on the particular C-Band satellite using a second polarization, and the first and second bit sequences also include a data management channel specifying a satellite, a carrier frequency, a polarization and a bit frame assignment for all available digital television channels, including digital television channels being transmitted from other C-Band satellites, said method comprising the steps of:

a) switching a mode of the adapter module to either an analog reception mode or a digital reception mode based on a mode reception command from a user;

b) in the analog reception mode, including the steps of:

(i) controlling a switch in the adapter module to couple a received RF signal containing the analog C-Band satellite broadcast television signals from the receiving antenna to the device;

(ii) receiving a television-ready signal from the device; and

(iii) providing the television-ready signal as an output from the adapter module; and

c) in the digital reception mode, including the steps of:

(i) receiving a digital television channel selection command from a user specifying a particular digital television channel to be provided as an output from the adapter module;

(ii) determining a particular carrier frequency, a particular polarization, and a particular bit frame assignment for the particular digital television channel based on information contained in the data management channel;

(iii) controlling the receiving antenna so that the receiving antenna outputs a polarized RF signal having the particular polarization;

(iv) controlling the switch so that an intermediate frequency signal corresponding to the polarized RF signal is coupled to a demodulator;

(v) controlling the demodulator so that the demodulator demodulates the intermediate frequency signal at the particular carrier frequency to form a bit sequence;

(vi) controlling a channel selector so that the channel selector demultiplexes a compressed version of the digital television channel from the bit sequence output by the demodulator based on the particular bit frame assignment;

(vii) restoring the compressed version of the particular digital television channel to the particular digital television channel; and

(viii) converting the particular digital television channel to a television-ready signal.

18. The method according to claim 17, wherein the digital reception mode further comprises the steps of:

(ix) using default values for the particular polarization, the transponder carrier frequency and the bit frame assignment, upon first switching from the analog reception mode to the digital reception mode; and

(x) reading the data management channel using the default values to determine the particular polarization, the particular transponder carrier frequency and the particular bit frame assignment for the particular digital television channel.

19. The method according to claim 17, wherein the digital reception mode further comprises the steps of:

(ix) storing default values for the particular polarization, the transponder carrier frequency and the bit frame assignment in the adapter module;

(x) using the default values for the particular polarization, the transponder carrier frequency and the bit frame assignment, upon first switching from the analog reception mode to the digital reception mode; and

(xi) updating dynamically the default values with information contained in the data management channel as long as the adapter module remains in the digital reception mode.

20. The method according to claim 19, wherein the digital television channels are reassigned dynamically at least among a plurality of C-Band satellite transponders, all available polarizations and all available bit frame assignments, and further comprising the steps of:

(xii) repeating steps c) (iii) and c) (v) through c) (viii) whenever the default values for the particular digital television channel are changed by said updating in step (ix).

21. A converter for coupling to an analog satellite television receiver, which includes an outdoor unit coupled to a satellite antenna and an indoor unit for coupling to a television or other video device, said converter comprising:

a) a coaxial switch having a first input being coupled to the outdoor unit for receiving a polarized intermediate frequency (IF) signal, having a second input being coupled to the indoor unit for receiving a steering control signal, having a third input being coupled to the indoor unit for receiving a polarization select signal, having a fourth input for receiving a second steering control signal, having a fifth input for receiving a second polarization select control signal, having a control input for switching the switch between a first position and a second position, having a first output being coupled to the indoor unit for providing the polarized IF signal to the indoor unit, having a second output being coupled to the outdoor unit for providing the steering control signal to the outdoor unit, having a third output being coupled to the outdoor unit for providing the polarization select signal to the outdoor unit, and having a fourth output for the polarized IF signal, wherein in the first position the coaxial switch couples the first input to the first output, couples the second and third inputs to the second and third outputs, respectively, and in the second position the coaxial switch couples the first input to the fourth output, and couples the fourth and fifth inputs to the second and third outputs, respectively;

b) a tuneable demodulator having a first input being coupled to the fourth output of the coaxial switch for receiving the polarized IF signal, having a second input for receiving a transponder select signal, and providing a bit sequence as an output, which bit sequence was modulated on a carrier frequency using a minimum shift keying modulation technique;

c) a demultiplexer having a first input being coupled to the output of the tuneable demodulator, having a second input for receiving a bit frame assignment for determining which compressed digital television channel within the bit sequence received from the tuneable demodulator is to be output, providing a compressed digital television signal as a first output, and providing a data management channel as a second output, which data management channel contains information necessary to receive all available digital television channels being broadcast from C-Band satellites in a particular viewing region;

d) a video decompressor having an input being coupled to the output of the demultiplexer and providing a restored version of the compressed digital television signal;

e) a digital-to-analog converter having an input being coupled to the video decompressor, converting the restored version of the compressed digital television signal to a video signal and providing the video signal as an output;

f) a splitter having a first input being coupled to the indoor unit for receiving a selected analog television signal, having a second input being coupled to the output of the digital-to-analog converter for receiving the video signal, and having an output for coupling to the television or other video device; and

g) a controller having a first input being coupled to the demultiplexer for receiving the data management channel, having a second input for receiving commands from a user, having a first output being coupled to the fourth input of the coaxial switch for sending the second steering control signal to the coaxial switch, having a second output being coupled to the fifth input of the coaxial switch for sending the second polarization select control signal to the coaxial switch, having a third output being coupled to the control input of the coaxial switch for controlling the position of the coaxial switch, having a fourth output being coupled to the second input of the tuneable demodulator for sending the transponder select signal to the tuneable demodulator, having a fifth output being coupled to the second input of the demultiplexer for sending the bit frame assignment, wherein upon a receipt of a command from the user to output a particular digital television signal, the control unit switches the coaxial switch via the control input to the second position, determines a first value for the steering control signal, a second value for the polarization select signal, a third value for the transponder select signal, and a fourth value for the bit frame assignment based on information contained in the data management channel, and outputs the first, second, third, and fourth values as the first, second, fourth and fifth outputs, respectively.

22. The converter according to claim 21, further comprising a decryptor unit having an input being coupled to the first output of the demultiplexer, and having an output being coupled to the digital-to-analog converter, wherein the compressed digital television signal is in encrypted form, and the decrypter

unencrypts the compressed digital television signal and provides the unencrypted compressed digital signal as an output.

23. The converter according to claim 21, further comprising an error correction unit having an input being coupled to the first output of the demultiplexer, and having an output being coupled to the digital-to-analog converter, wherein the error correction unit corrects errors in the compressed digital television signal and provides the corrected compressed digital signal as an output.

24. The converter according to claim 21, further comprising text overlaying device having a first input being coupled to the control unit for receiving text messages from the control unit, having a second input for receiving the restored version of the compressed digital television signal and providing a combined text and video digital television signal as an output to the digital-to-analog converter.

25. A method for converting from analog C-Band television service to digital C-band television service without interrupting service to users, comprising:

a) converting a first transponder on a satellite to digital television service by modulating a first plurality of compressed digital television channels and a data management channel on a first carrier frequency for the first transponder, wherein the data management channel contains information for all channels provided by the digital C-Band television service, which information includes receiver parameters necessary to receive each of the first plurality of compressed digital television channels;

b) switching between analog C-Band television service and digital C-Band television service in an adapter module in response to a service selection signal from a user;

c) receiving a digital television channel selected by the user by modifying a digital receiver according to the receiver parameters for the digital television channel selected by the user contained in the data management channel;

d) converting a second transponder on the satellite to digital television service by modulating a second plurality of compressed digital television signals and said data management channel on a second carrier frequency for the second transponder;

e) updating the information in the data management channel to provide updated receiver parameters necessary to receive each of the compressed digital television channels in the first and second plurality of digital television channels; and

f) modifying the digital receiver according to the updated receiver parameters.

26. The method according to claim 25 further comprising the steps of:

g) moving a subset of the channels in the first plurality of compressed digital television channels to the second plurality of compressed digital television channels while simultaneously performing the step d) of converting.

27. The method according to claim 26, wherein the number of channels in the first and second plurality of compressed digital television channels after step g) of moving is performed is the same as the number of channels in the first plurality of compressed digital television signals before the steps g) and d) are performed.

28. The method according to claim 25, further comprising the steps of:

g) simultaneously reducing the number of channels in the first plurality of compressed digital television channels while increasing the number of transponders converted according to step d) of converting so that the total number of compressed digital television signals provided by the digital television service never decreases.

29. The method according to claim 28, wherein steps e) and f) are continuously performed so that user intervention is not required when step g) is performed.

30. An adapter for coupling to a TVRO antenna and an indoor unit of a C-band satellite broadcast receiving system to allow reception of both analog C-band television programming, and digital C-band television programming, said adapter comprising:

a) means for switching between a first mode for receiving the analog C-band television programming and a second mode for receiving the digital C-band television programming;

b) means for passing the analog C-band television programming to the indoor unit in the first mode;

c) means for receiving the digital C-band television programming in the second mode; and

d) means for controlling the switching means and the receiving means based on a viewer preference.

31. An apparatus for converting an analog C-band receiver into an analog and digital C-band receiver, comprising:

a) a first input for receiving a television signal containing with either an analog signal or a digital signal;

b) a second input for receiving a viewer channel selection signal indicating whether a viewer has selected a digital television channel or an analog television channel;

c) a first output for outputting the television signal when the viewer channel selection signal indicates the viewer has selected an analog television channel, said first output for coupling to said analog C-band receiver;

d) a second output for outputting a television-ready signal, said second output for coupling to a video device;

e) a third input for receiving a television-ready signal from the analog C-band receiver;

f) a digital C-band receiver converting the digital signal into a second television-ready signal and outputting a second television-ready signal to the second output when the viewer channel selection signal indicates the viewer has selected a digital television channel, wherein said second output outputs either the first or second television-ready signal depending on whether the viewer has selected an analog or digital television channel, respectively.

32. A system for receiving both analog and digital C-band television broadcasts, comprising:

a) an antenna;

b) an outdoor unit coupled to the antenna and converting a received RF signal to an IF signal;

c) a switch having two positions, and being coupled to the outdoor unit;

d) an analog receiver being coupled to the first position of the switch and converting the IF signal to a TV ready signal;

e) a digital receiver being coupled to the second position of the switch and converting the IF signal to a TV ready signal; and

f) a controller setting the position of the switch based on user preference.

33. An antenna for receiving a signal transmitted from a constellation of satellites, which includes a central satellite and a plurality of satellites spaced at regular intervals from the central satellite, said antenna comprising:

two nulls matched to at least two pairs of satellites in the constellation that are immediately adjacent to the central satellite, wherein the two nulls prevent signals from said at least two pairs of adjacent satellites from interfering with a signal being transmitted from the central satellite.

34. An antenna for receiving a signal from a central satellite in a constellation of satellites, which includes the central satellite and a plurality of satellites spaced at regular angular intervals from the central satellite relative to the antenna, said antenna comprising:

a) a central reflector;

b) a first side reflector;

c) a second side reflector;

d) a first gap between the central reflector and the first side reflector; and

e) a second gap between the central reflector and the second side reflector, wherein said first and second gaps create at least two nulls in received energy, which two nulls inhibit signals being transmitted from at least two pairs of satellites in the constellation that are immediately adjacent to the central satellite.

35. A method for receiving a signal being transmitted from a constellation of satellites, which includes a central satellite and a plurality of satellites spaced at regular angular intervals from the central satellite relative to a receiving antenna, said method comprising the steps of:

a) providing gain for a signal being transmitted from the central satellite; and

b) inhibiting signals being transmitted from the plurality of satellites that are independent of the signal being transmitted from the central satellite.

36. A method for sending a quantity of data representing a video signal from a ground transmitter to a terrestrial antenna via a satellite, said method comprising the steps of:

a) compressing the quantity of data to form a quantity of compressed data;

b) modulating the quantity of compressed data into a broadband power efficient signal;

c) transmitting the broadband power efficient signal to the satellite;

d) retransmitting the broadband power efficient signal from the satellite;

e) receiving the broadband signal with the terrestrial antenna; and

f) matching nulls in an antenna pattern of the terrestrial antenna to sources of potential interference, wherein the nulls prevent signals from said sources of interference from interfering with the broadband signal being retransmitted in step d).

37. A system for transmitting a video signal to a terrestrial user via a main satellite within a constellation of satellites, which includes at least two pairs of satellites adjacent to the main satellite and spaced at regular angular intervals relative to the terrestrial user, comprising:

a) an analog to digital converter converting the video signal to a digital signal;

b) a data compressor being coupled to the analog to digital converter and compressing the digital signal to form a compressed digital signal;

c) a shaped frequency shift keyed modulator being coupled to the data compressor and modulating the compressed digital signal into a wideband analog shaped frequency shift keyed signal that contains 3 to 8 dB of coding gain;

d) a satellite transmitter being coupled to the shaped frequency shift keyed modulator and outputting a wideband RF signal;

e) a satellite antenna radiating the wideband RF signal to the main satellite within the constellation of satellites, which wideband RF signal is retransmitted by the main satellite back to earth;

f) a terrestrial antenna receiving the wideband RF signal, outputting a received signal, and having a diameter such that a beamwidth of the terrestrial antenna encompasses the main satellite and the at least the two pairs of adjacent satellites in the constellation;

g) a shaped frequency shift keyed demodulator being coupled to the terrestrial antenna and demodulating the received signal into a received compressed digital signal;

h) a data decompressor being coupled to the shaped frequency shift keyed demodulator and converting the received compressed digital signal into a received digital signal; and

i) a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a received video signal available to the user.

38. A system for transmitting a video signal to a terrestrial user via a main satellite within a constellation of satellites, which includes at least two pairs

of satellites adjacent to the main satellite and spaced at regular angular intervals relative to the terrestrial user, comprising:

a) an analog to digital converter converting the video signal to a digital signal;

b) a data compressor being coupled to the analog to digital converter and compressing the digital signal to form a compressed digital signal;

c) a shaped frequency shift keyed modulator being coupled to the data compressor and modulating the compressed digital signal into a wideband analog shaped frequency shift keyed signal that contains 3 to 8 dB of coding gain;

d) a satellite transmitter being coupled to the shaped frequency shift keyed modulator and outputting a wideband RF signal;

e) a satellite antenna radiating the wideband RF signal to the main satellite, which wideband RF signal is retransmitted by the main satellite back to earth;

f) a terrestrial antenna receiving the wideband RF signal, outputting a received signal, having a diameter such that a beamwidth of the terrestrial antenna encompasses the main satellite and the at least two pairs of adjacent satellites in the constellation, and including an irregularly shaped contour that provides normal gain for a signal from the main satellite and low gain nulls for signals from the at least two pairs of adjacent satellites, wherein the low gain nulls prevent signals being transmitted from the at least two pairs of adjacent satellites from interfering with a signal being transmitted from the main satellite;

g) a shaped frequency shift keyed demodulator being coupled to the terrestrial antenna and demodulating the received signal into a received compressed digital signal;

h) a data decompressor being coupled to the shaped frequency shift keyed demodulator and converting the received compressed digital signal into a received digital signal; and

i) a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a received video signal available to the user.

39. A receiver for receiving a video signal being broadcast via a satellite to a terrestrial antenna as a wideband power efficient signal, comprising:

a) a shaped frequency shift keyed demodulator being coupled to the terrestrial antenna and demodulating a received shaped frequency shift keyed signal being output from the terrestrial antenna into a received compressed digital signal;

b) a data decompressor being coupled to the shaped frequency shift keyed demodulator and decompressing the received compressed digital signal into a received digital signal; and

c) a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a signal resembling the video signal being broadcast from the satellite.

40. A ground station for receiving a television signal being broadcast as a wideband power efficient RF signal via a main satellite within a constellation of satellites, which includes at least two pairs of adjacent satellites adjacent to the main satellite and spaced at regular angular intervals from the main satellite relative to the ground station, said ground station comprising:

a) a terrestrial antenna receiving the television signal being broadcast from the constellation of satellites, outputting a received signal, and having a diameter such that a beamwidth of the terrestrial antenna encompasses the main satellite and the at least the two pairs of adjacent satellites;

b) a shaped frequency shift keyed demodulator being coupled to the terrestrial antenna and demodulating the received signal into a received compressed digital signal, wherein the received signal contains 3 to 8 dB of coding gain;

c) a data decompressor being coupled to the shaped frequency shift keyed demodulator and converting the received compressed digital signal into a received digital signal; and

d) a digital to analog converter being coupled to the data decompressor and converting the received digital signal into a received television signal available to the user.

41. A satellite within a constellation of satellites for retransmitting a signal to a terrestrial antenna, which has a diameter such that a beamwidth of the terrestrial antenna encompasses the satellite as well as other satellites within the constellation of satellites, said satellite comprising:

a) a satellite receiver receiving a wideband power efficient RF signal from a ground transmitter, wherein the wideband power efficient signal contains 3 to 8 dB of coding gain; and

b) a satellite transmitter being coupled to the satellite receiver and retransmitting the wideband power efficient RF signal at a power level such that when the wideband power efficient RF signal reaches the earth the wideband power efficient RF signal lies within FCC limitations on satellite transmissions.

42. An apparatus for transmitting a television signal to a satellite within a constellation of satellites, for broadcast back to earth to a terrestrial antenna, said apparatus comprising:

a) an analog to digital converter converting the television signal to a digital television signal;

b) a data compressor being coupled to the analog to digital converter and compressing the digital television signal to a compressed digital signal;

c) a modulator modulating the compressed digital signal into a wideband power efficient signal that contains 3 to 8 dB of coding gain while simultaneously selecting a number of channels to transmit in combination with EIRP to automatically provide the necessary coding gain;

d) an RF transmitter being coupled to the modulator and transmitting the wideband power efficient signal to a satellite at an RF power level such that when the wideband power efficient signal is retransmitted from the satellite and reaches earth the wideband power efficient signal lies within FCC limitations on satellite transmissions at ground level.

43. A method for transmitting a signal from a ground station to a system of satellites with varying EIRP's for retransmitting the signal back to earth, said method comprising the steps of:

a) decreasing a data rate of the signal for satellites with lower EIRPs; b) increasing the data rate of the signal for satellites with higher EIRPs; and

c) maintaining a bandwidth of the signal constant so that when the signal is retransmitted from one of the satellites with a weaker EIRP the signal has increased coding gain relative to the same signal transmitted from one of the satellites with a higher EIRP, whereby maximum channel capacity is achieved with a given size antenna but unequal satellite EIRP's.

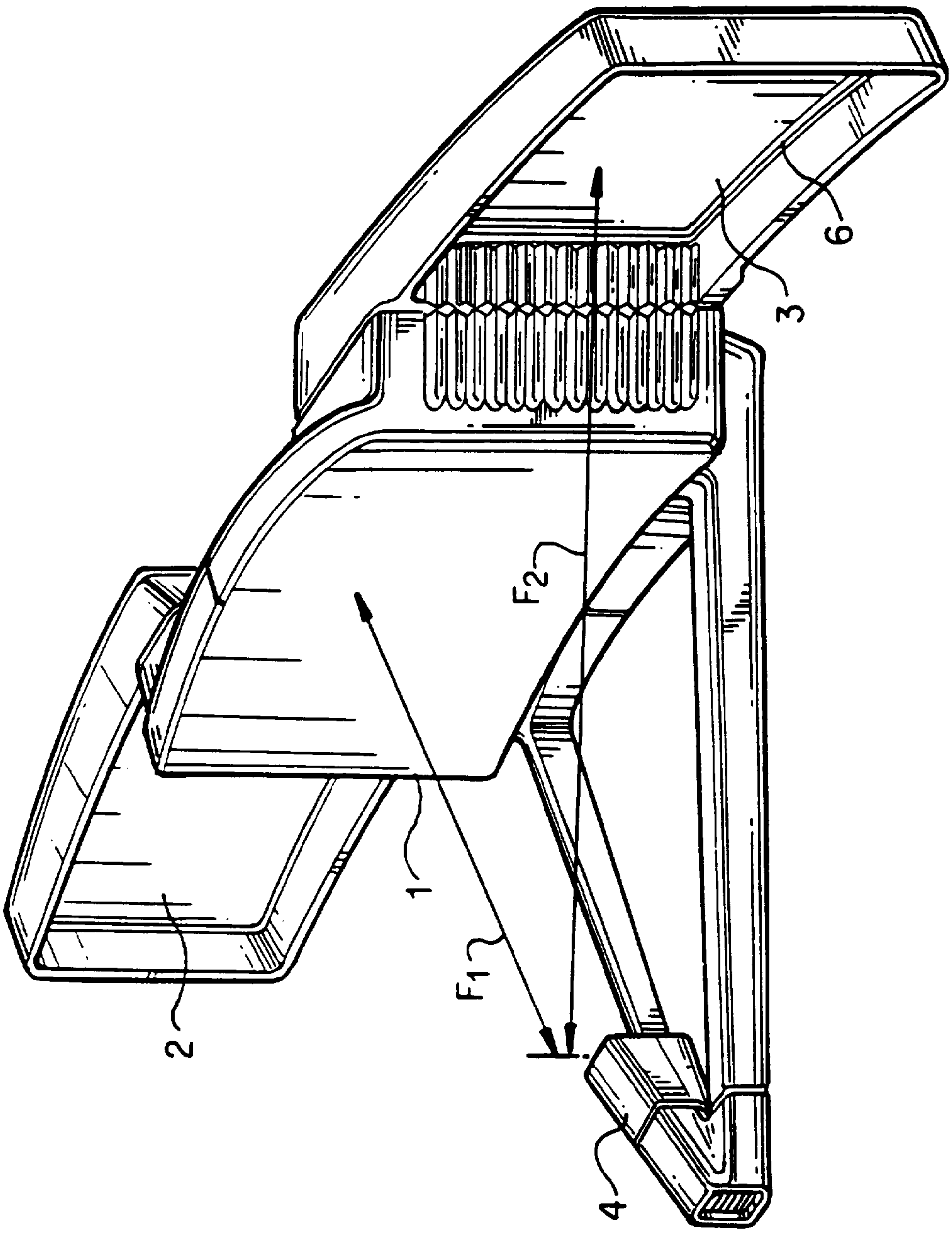


FIG. 1

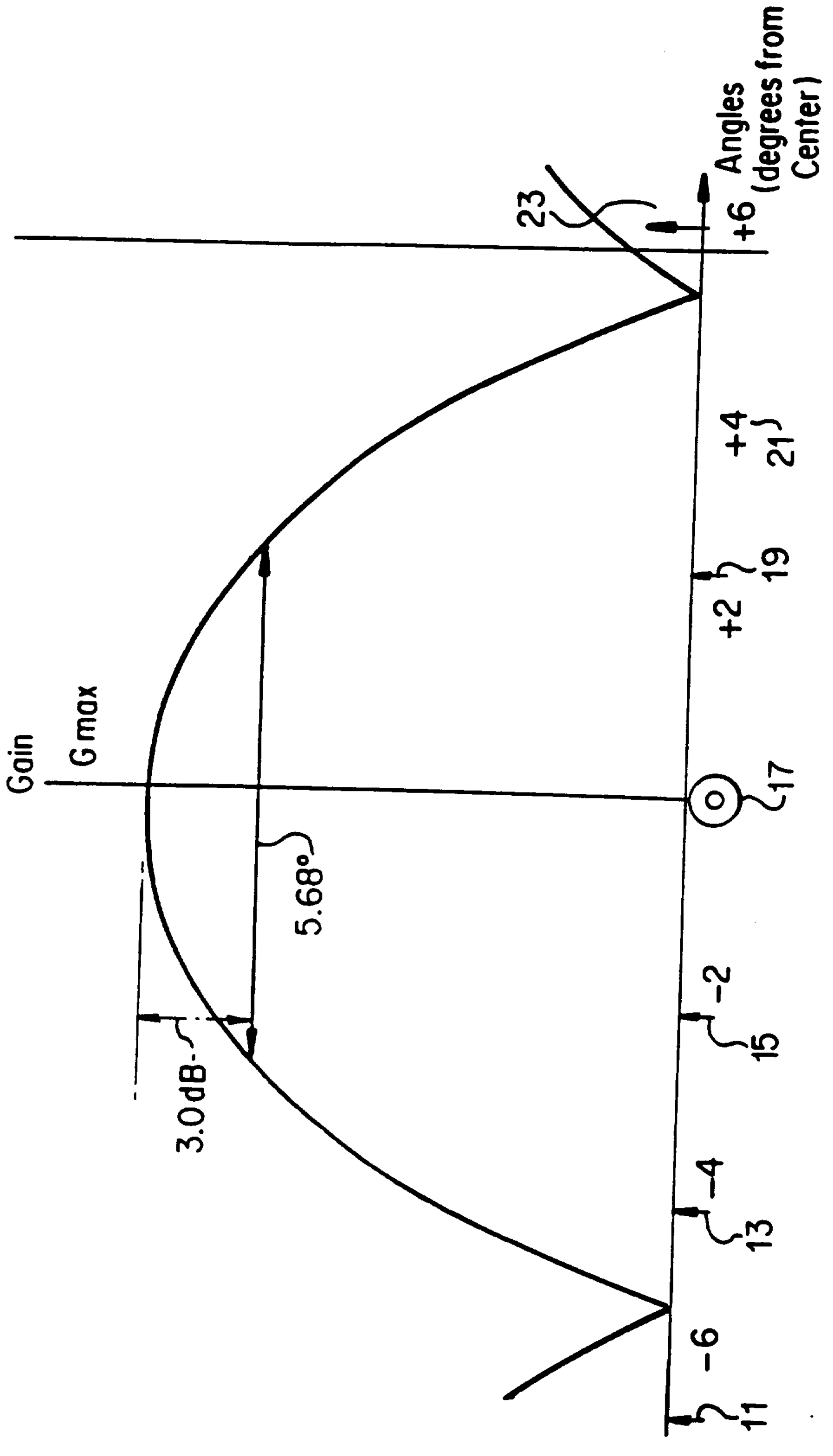

Gain
G max
Angles (degrees from Center)
3.0dB
5.68°
-6
-4
-2
+2
+4
+6
11
13
15
17
19
21
23

FIG. 2

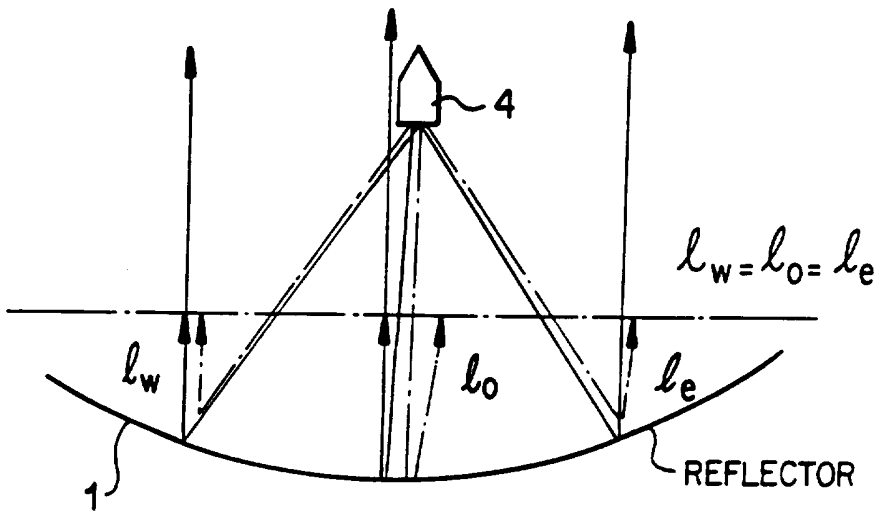

4
$\ell_w = \ell_o = \ell_e$
ℓ_w
ℓ_o
ℓ_e
1
REFLECTOR

FIG.3

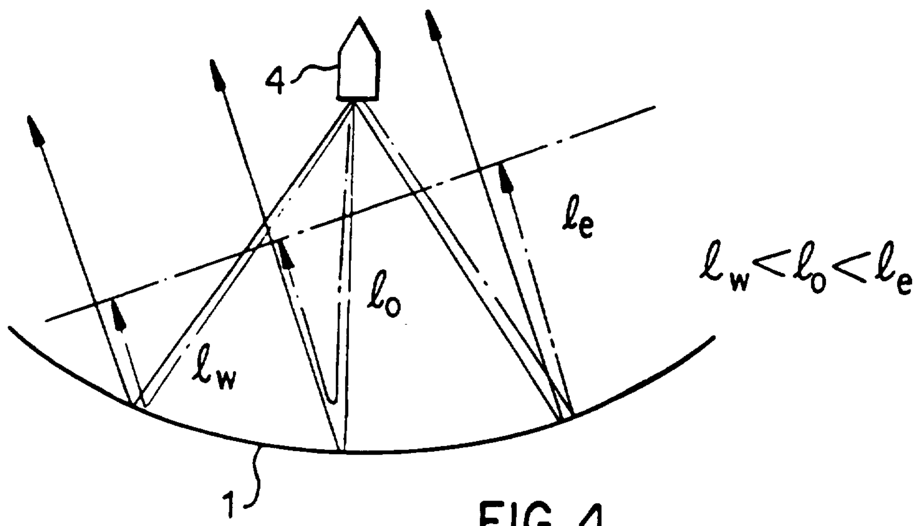

4
ℓ_e
$\ell_w < \ell_o < \ell_e$
ℓ_o
ℓ_w
1

FIG.4

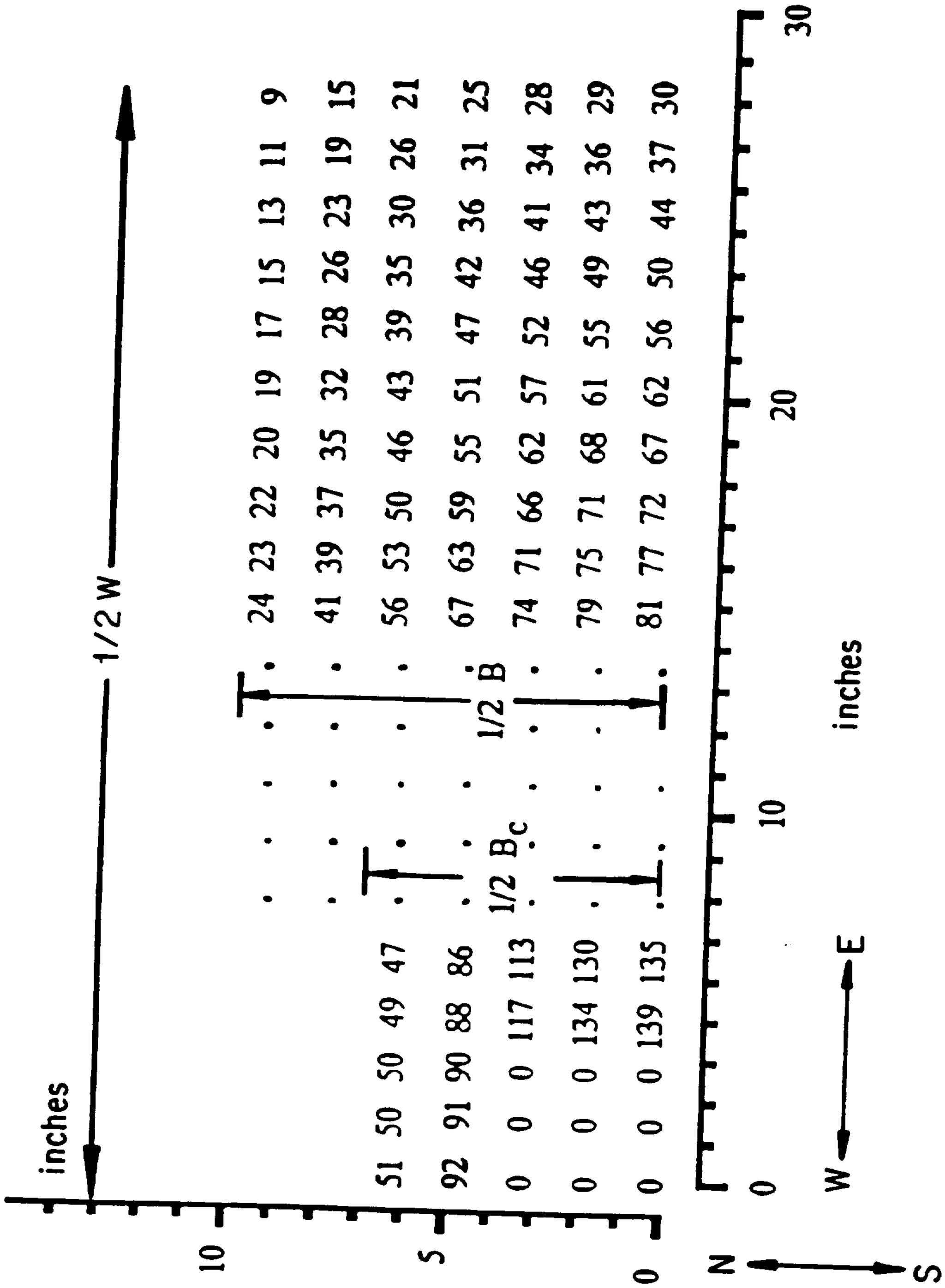


FIG. 5

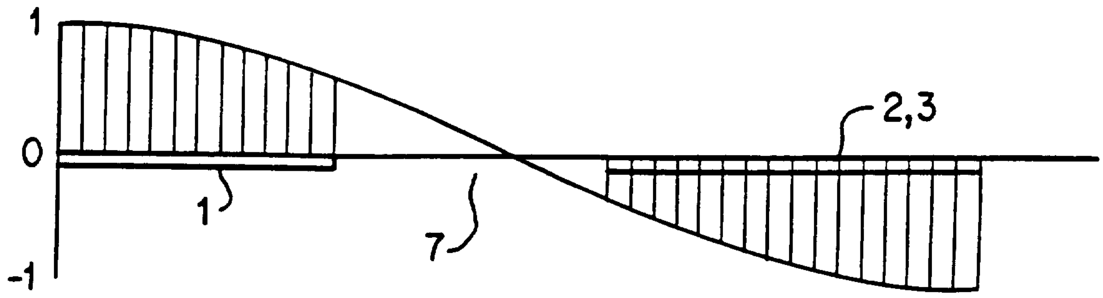


FIG. 6

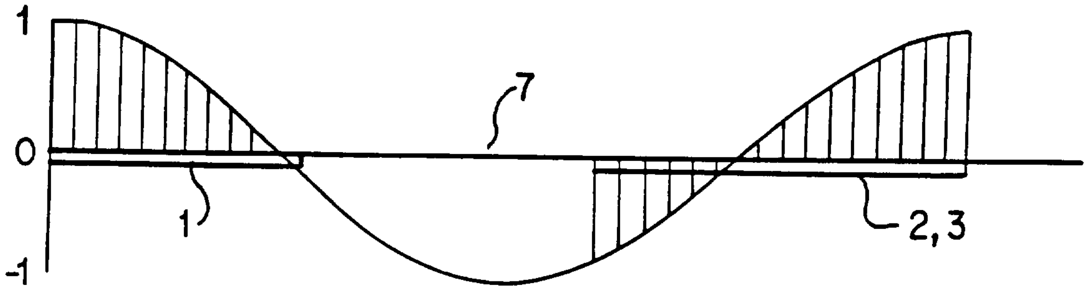


FIG.7

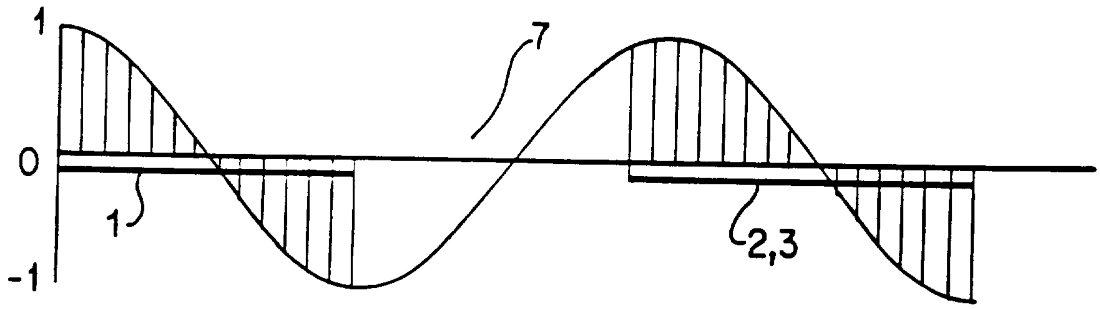


FIG. 8

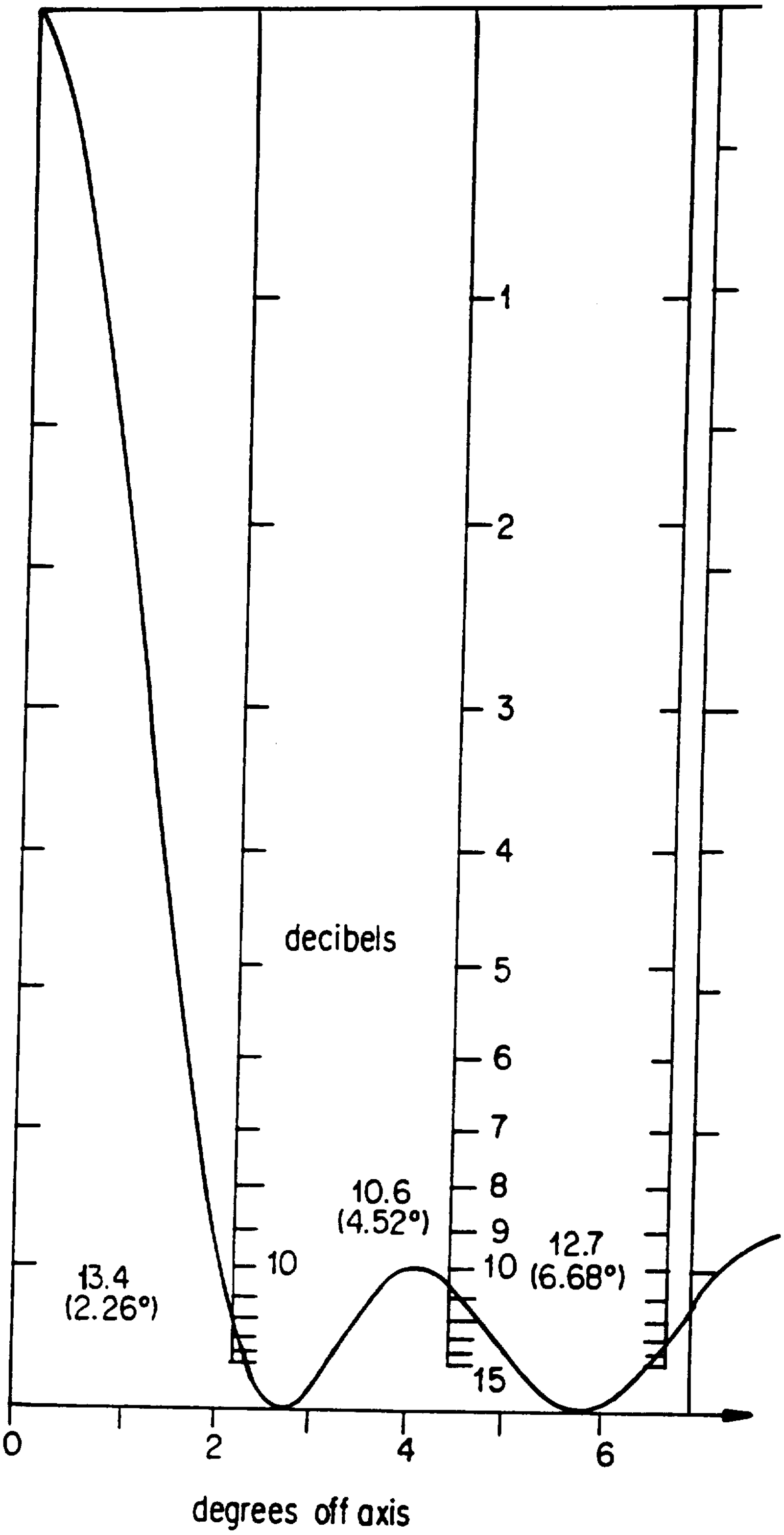

1
2
3
4
5
6
7
8
9
10
15
decibels
13.4
(2.26°)
10.6
(4.52°)
12.7
(6.68°)
0
2
4
6
degrees off axis

FIG. 9

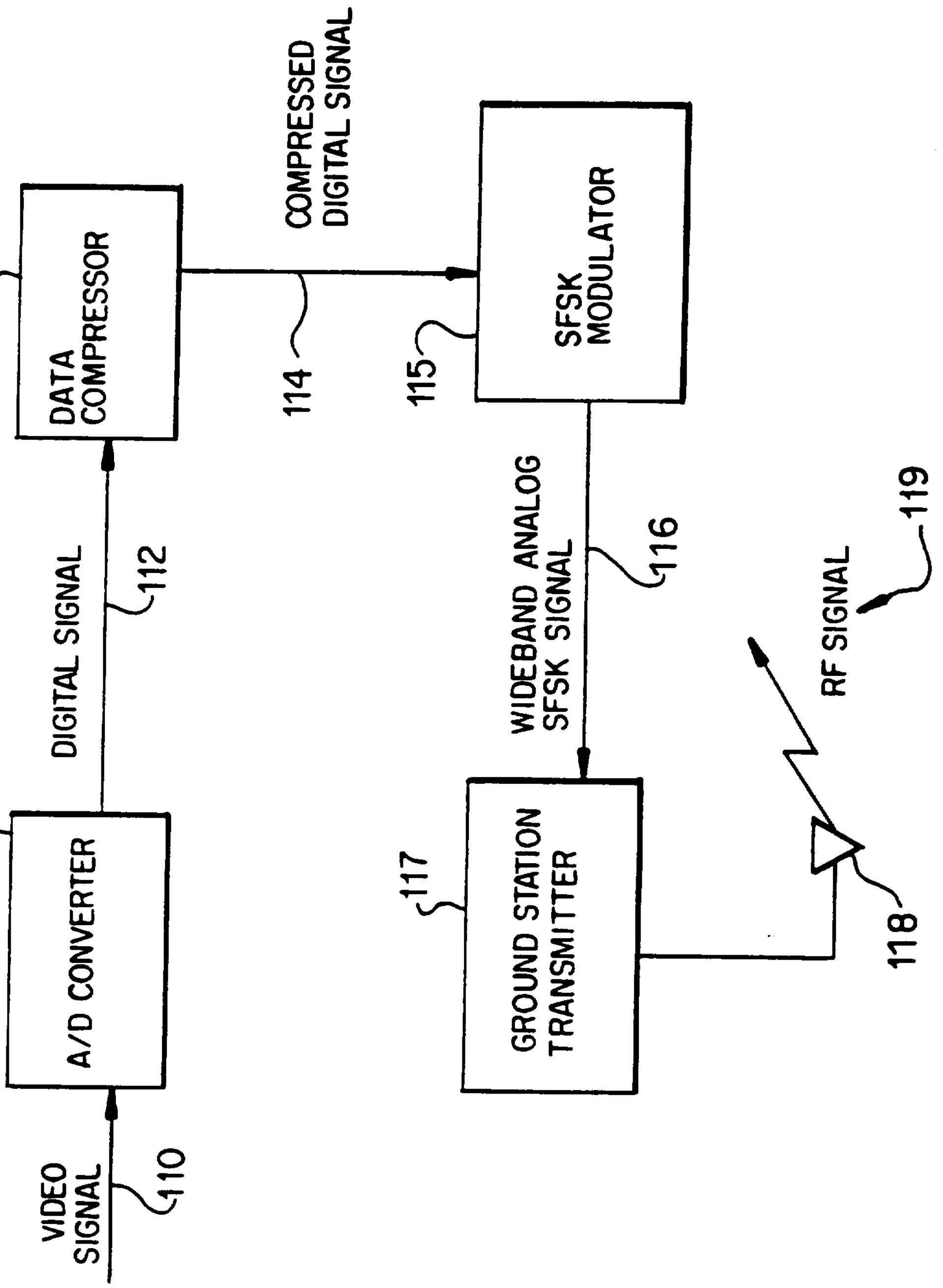

VIDEO SIGNAL
110
A/D CONVERTER
111
DIGITAL SIGNAL
112
DATA COMPRESSOR
113
COMPRESSED DIGITAL SIGNAL
114
SFSK MODULATOR
115
WIDEBAND ANALOG SFSK SIGNAL
116
GROUND STATION TRANSMITTER
117
118
RF SIGNAL
119

FIG. 10

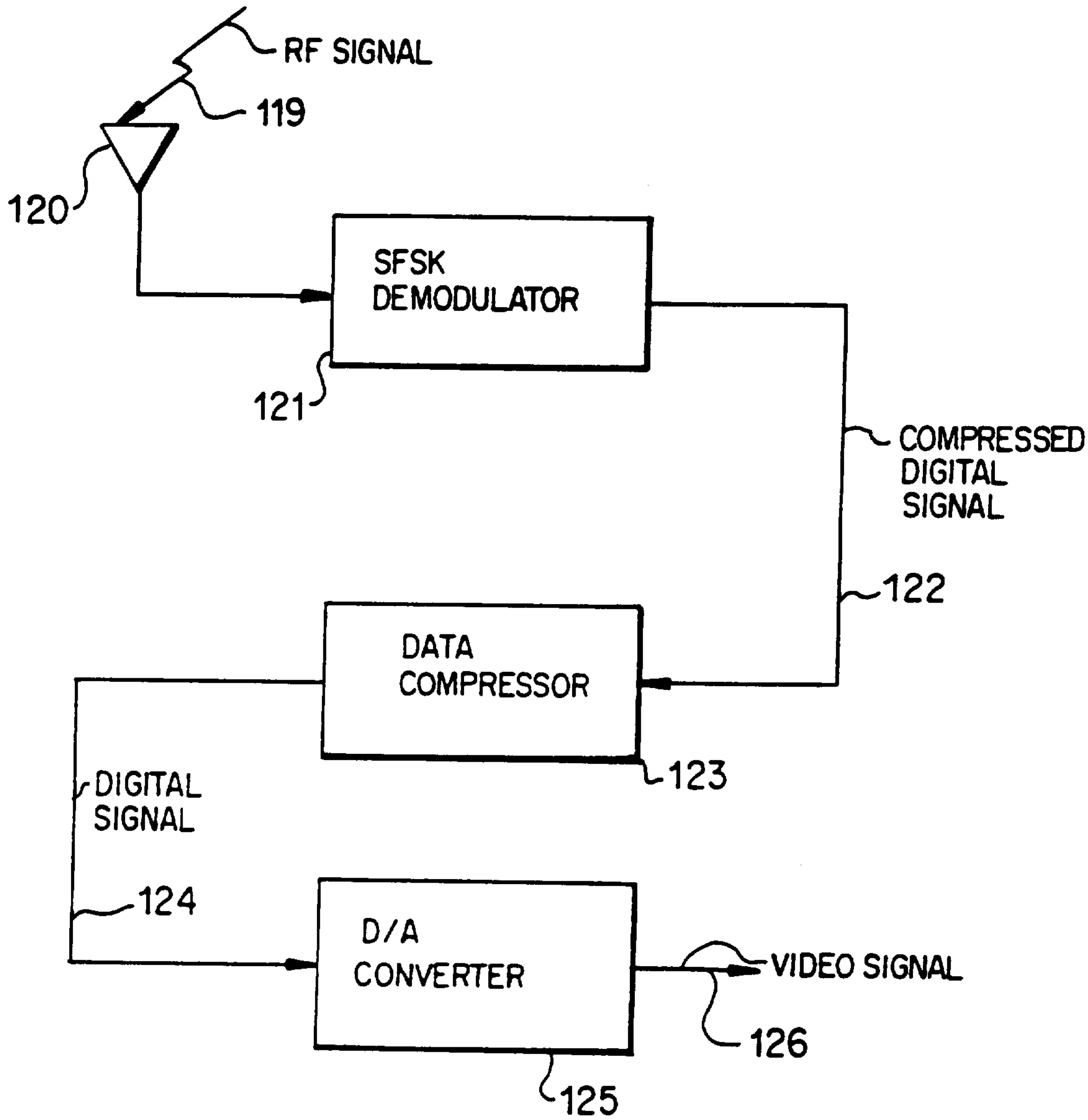

RF SIGNAL
119
120
SFSK DEMODULATOR
121
COMPRESSED DIGITAL SIGNAL
122
DATA COMPRESSOR
123
DIGITAL SIGNAL
124
D/A CONVERTER
VIDEO SIGNAL
126
125

FIG. 11

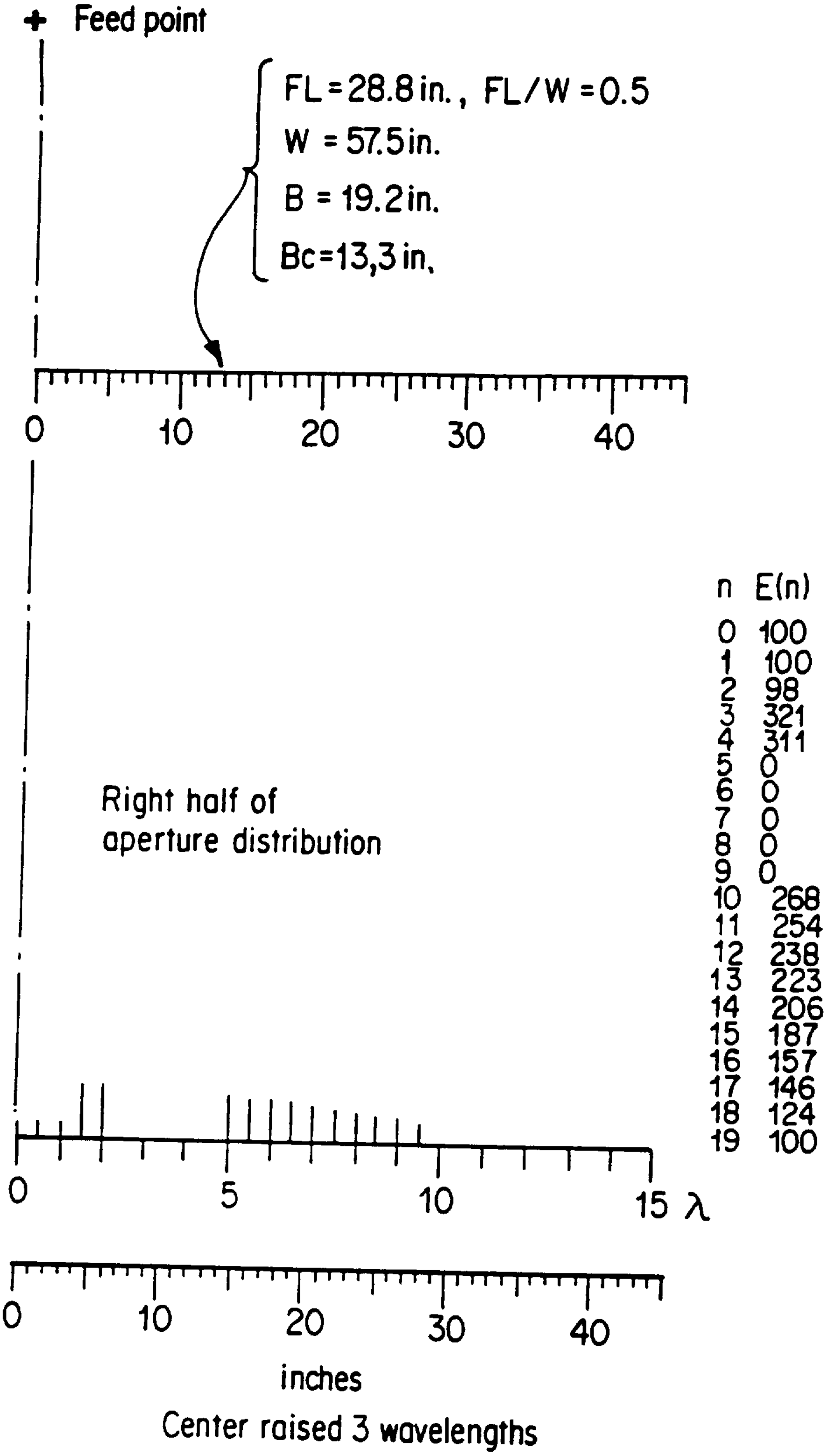

Feed point
FL=28.8 in., FL/W=0.5
W = 57.5 in.
B = 19.2 in.
Bc=13,3 in.
0 10 20 30 40
n E(n)
0 100
1 100
2 98
3 321
4 311
5 0
6 0
7 0
8 0
9 0
10 268
11 254
12 238
13 223
14 206
15 187
16 157
17 146
18 124
19 100
Right half of aperture distribution
0 5 10 15 λ
0 10 20 30 40
inches
Center raised 3 wavelengths

FIG. 12

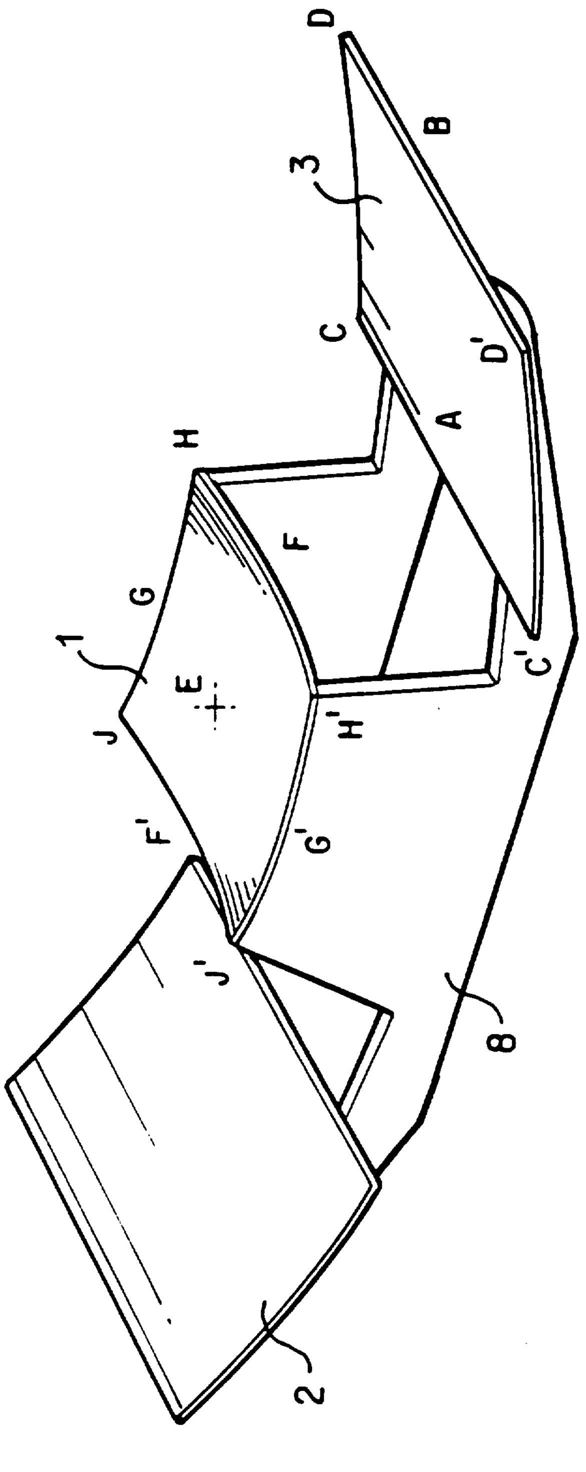


FIG. 13

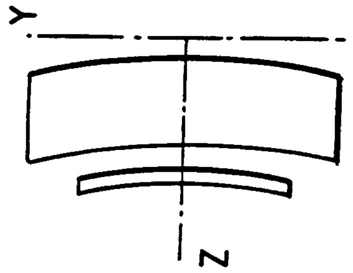


FIG.14C

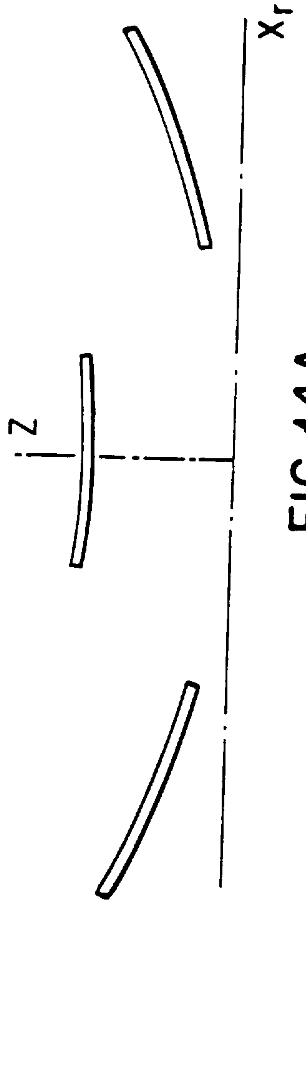


FIG.14A

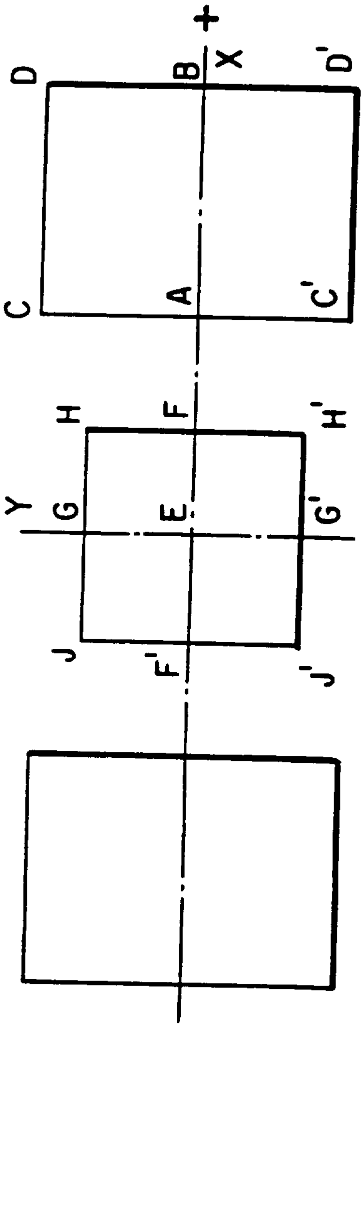


FIG. 14B

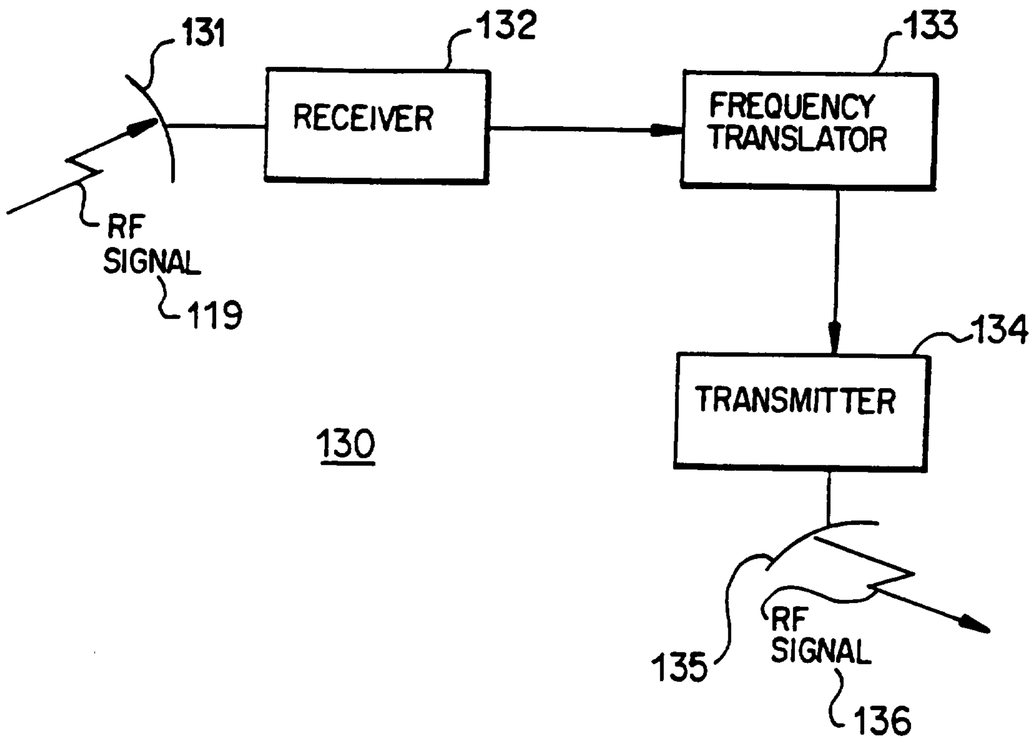
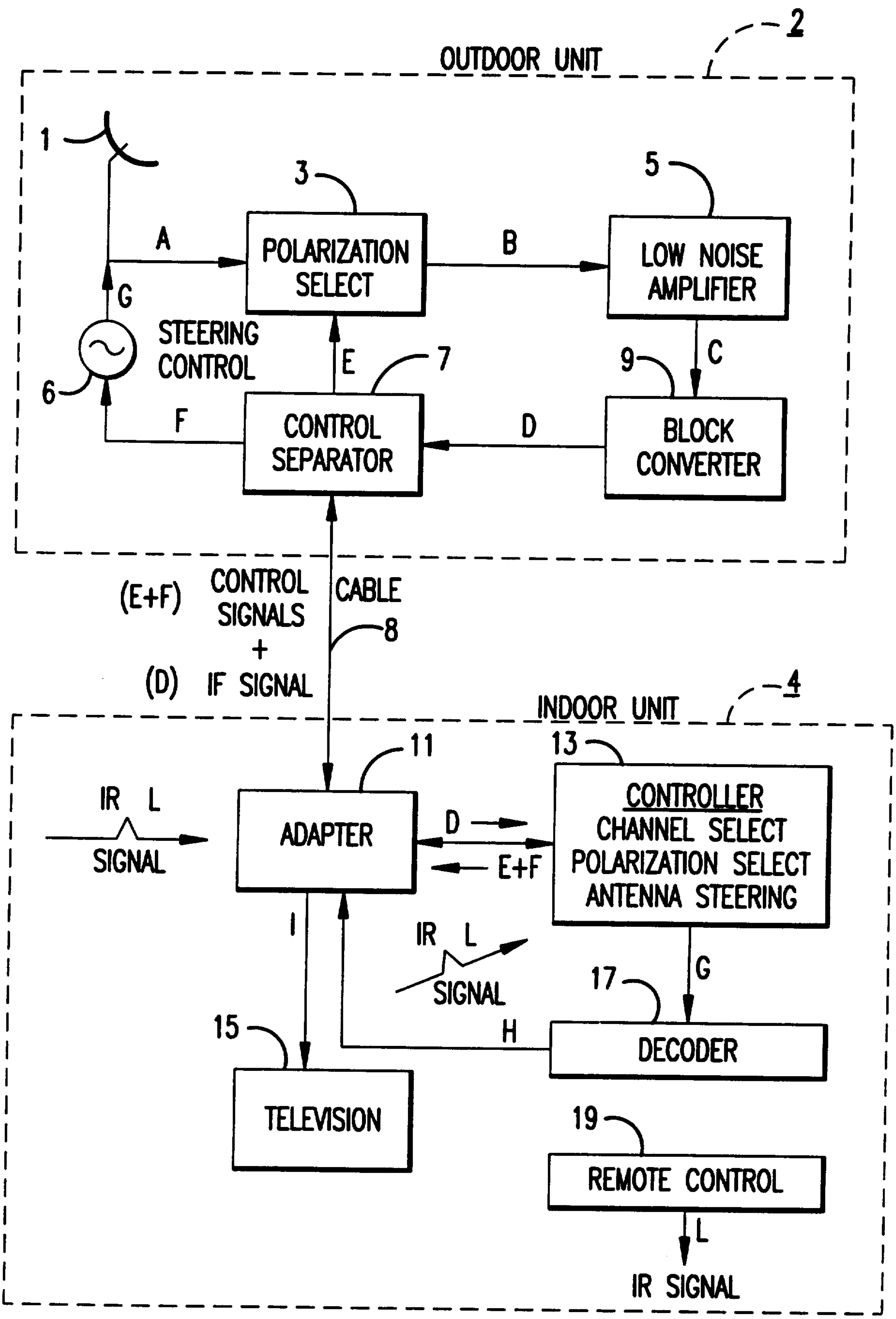

131
132
RECEIVER
133
FREQUENCY TRANSLATOR
RF SIGNAL
119
134
TRANSMITTER
130
135
RF SIGNAL
136

FIG. 15



OUTDOOR UNIT
2
1
3
POLARIZATION SELECT
5
LOW NOISE AMPLIFIER
A
B
G
STEERING CONTROL
6
E
7
C
9
CONTROL SEPARATOR
F
D
BLOCK CONVERTER
(E+F) CONTROL SIGNALS
+
(D) IF SIGNAL
CABLE
8
INDOOR UNIT
4
11
13
IR L
SIGNAL
ADAPTER
D
E+F
CONTROLLER
CHANNEL SELECT
POLARIZATION SELECT
ANTENNA STEERING
I
IR L
SIGNAL
G
17
15
H
DECODER
TELEVISION
19
REMOTE CONTROL
L
IR SIGNAL

FIG.16

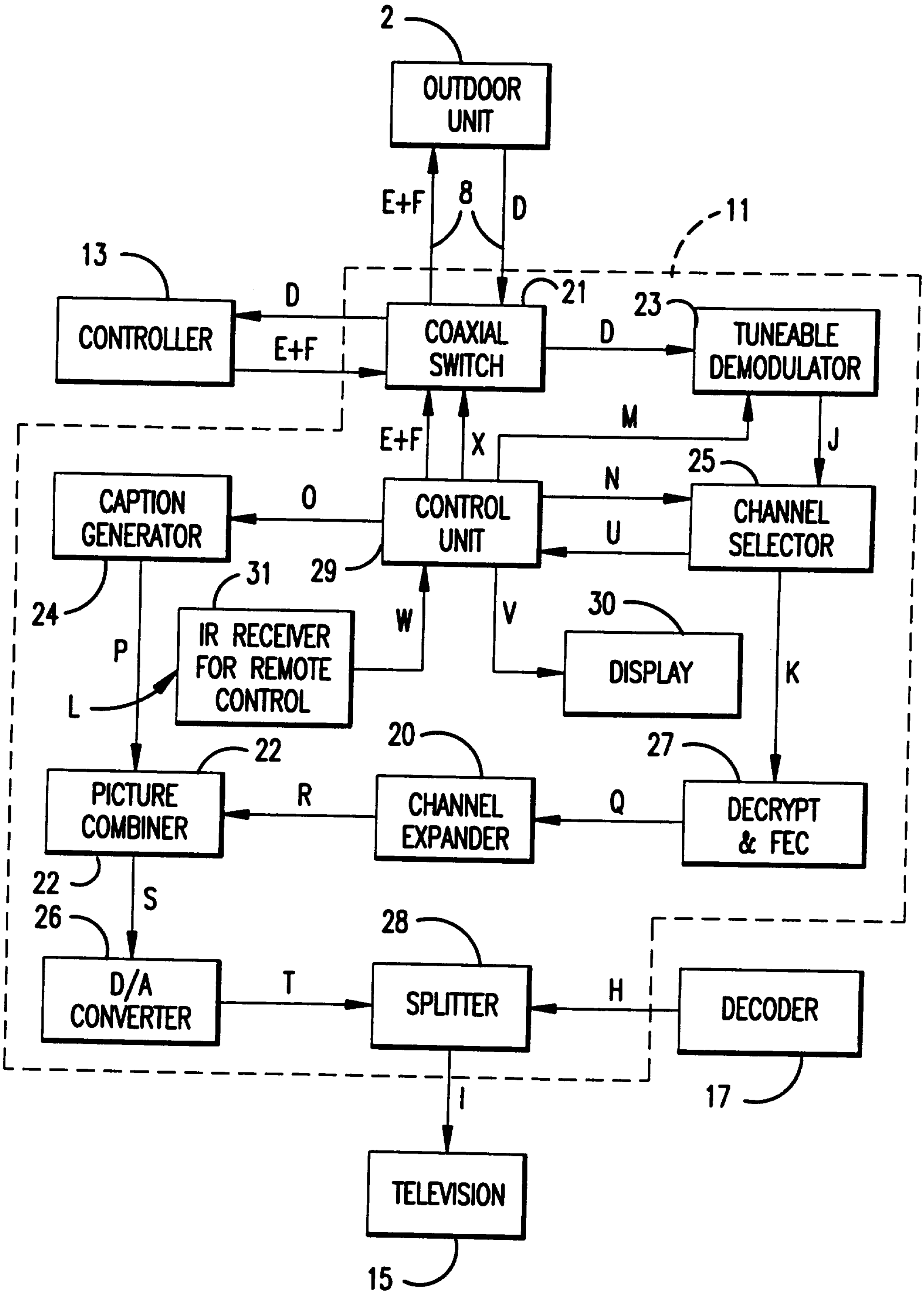

2
OUTDOOR UNIT
E+F
8
D
11
13
CONTROLLER
D
E+F
COAXIAL SWITCH
21
D
23
TUNEABLE DEMODULATOR
E+F
X
M
J
25
CAPTION GENERATOR
O
CONTROL UNIT
N
U
CHANNEL SELECTOR
24
31
29
IR RECEIVER FOR REMOTE CONTROL
W
V
30
DISPLAY
P
L
K
22
20
27
PICTURE COMBINER
R
CHANNEL EXPANDER
Q
DECRYPT & FEC
22
S
26
28
D/A CONVERTER
T
SPLITTER
H
DECODER
17
I
TELEVISION
15

FIG. 17

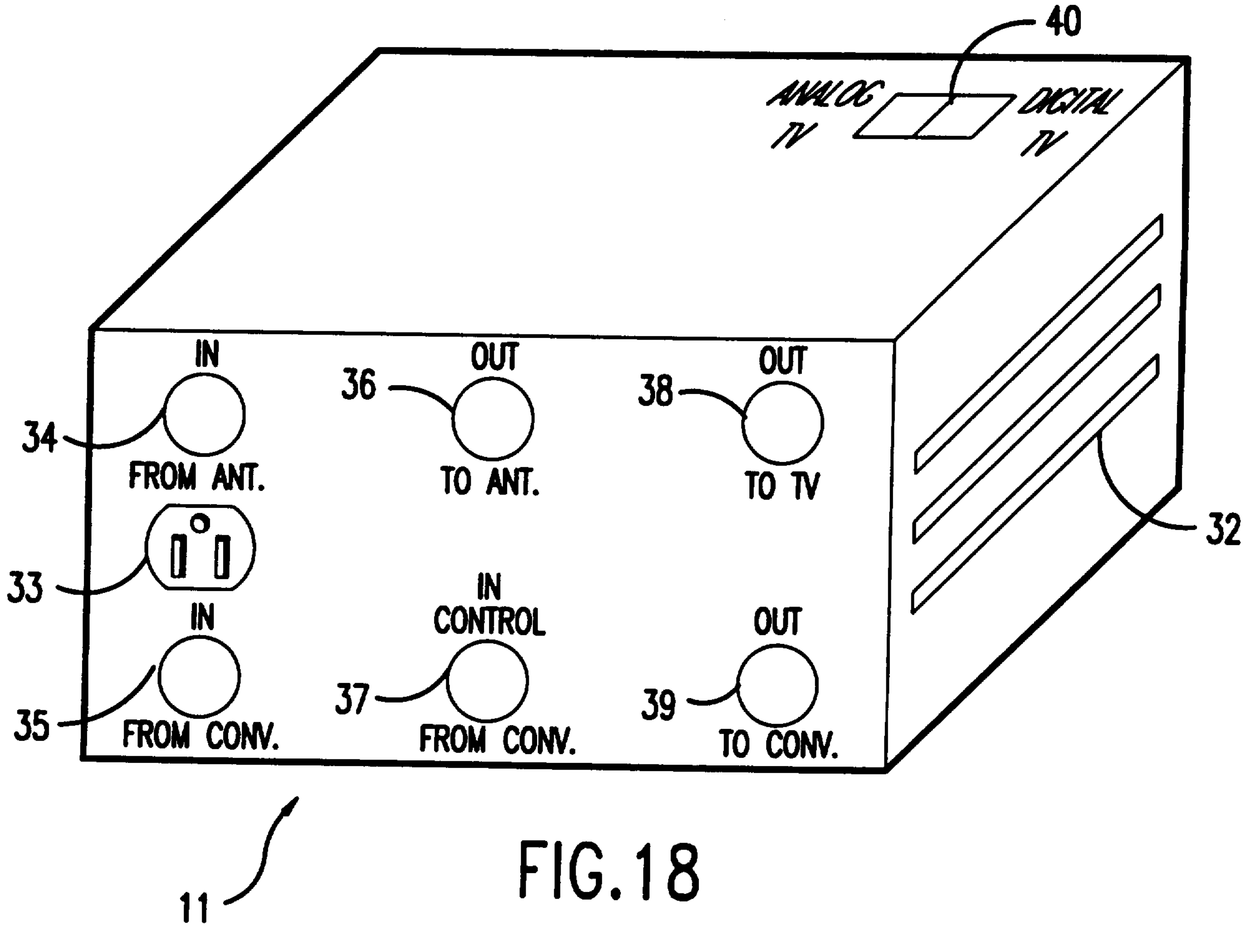

40
ANALOG TV
DIGITAL TV
IN
FROM ANT.
34
OUT
TO ANT.
36
OUT
TO TV
38
32
33
IN
FROM CONV.
35
IN
CONTROL
FROM CONV.
37
OUT
TO CONV.
39
11

FIG.18

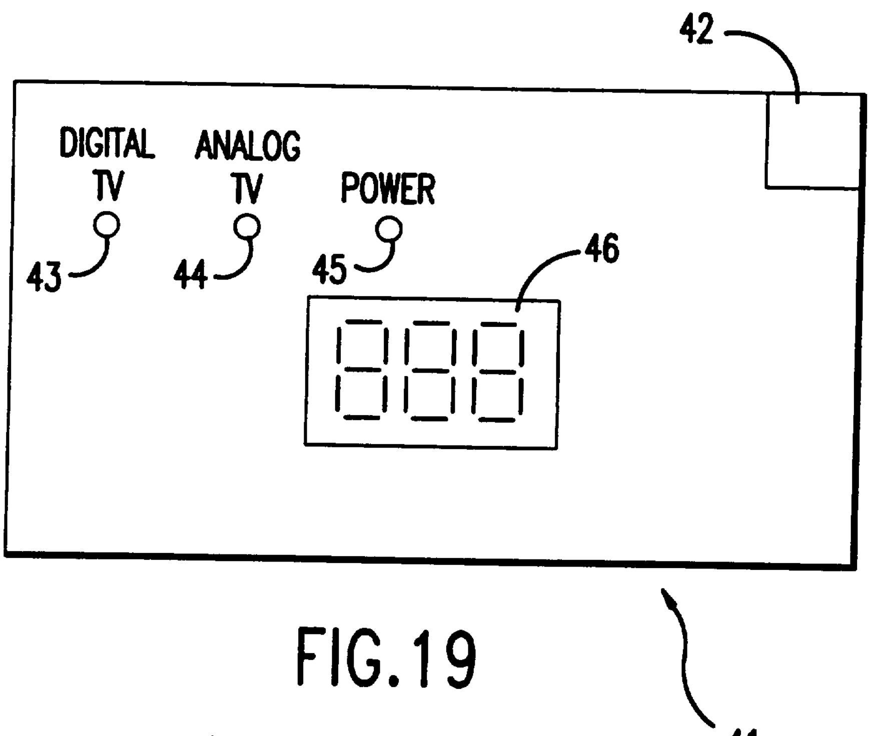

42
DIGITAL TV
ANALOG TV
POWER
43
44
45
46
41

FIG.19

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/08160

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H04N 7/20
US CL : 348/706, 724, 726; 455/3.2, 12.1, 13.3, 281, 293; 375/303, 334
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : Please See Extra Sheet.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Please See Extra Sheet.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,345,591 (TSURUMAKI ET AL) 06 September 1994, abstract, figures 4, 8, 14.	17
A	US, A, 5,231,494 (WACHOB) 27 July 1993, abstract and figures 1-2.	1, 11, 16, 21, 37, 39, 42
A	US, A, 5,345,473 (BERG) 06 September 1994, abstract and figure 1.	37, 40-42
A, E	US, A, 5,438,590 (TZUKERMAN ET AL) 01 August 1995, abstract and figure 1.	37-40, 42
A, P	US, A, 5,418,815 (ISHIKAWA ET AL) 23 May 1995, abstract and figure 6.	30-32
A	FR, A, 2-629-973 (MIKRU) 13 October 1989, abstract and figures 1-2.	1, 16, 21, 25

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be part of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

04 OCTOBER 1995

Date of mailing of the international search report

21 DEC 1995

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
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Form PCT/ISA/210 (second sheet)(July 1992)★

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/08160

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP, A, 6-276527 (FURUKAWA) 30 September 1994, abstract and figure 1.	1-2, 11, 16, 21
A	US, A, 5,237,610 (GAMMIE ET AL) 17 August 1993, abstract and figure 7.	22
A	US, A, 5,379,320 (FERNANDES ET AL) 03 January 1995, abstract, figures 4, 8, 9 & 12.	25, 37-40, 42
A	US, A, 5,355,512 (PROFERA, Jr.) 11 October 1994 See figure 1a and col. 4, lines 15-57	33-36, 41 and 43
A,E	US, A, 5,455,960 (PELCHAT et al) 03 October 1995 See figure 1 and col. 1-2	33-36, 41 and 43

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/08160

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest
☐ The additional search fees were accompanied by the applicant's protest.
☒ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/08160

B. FIELDS SEARCHED
Minimum documentation searched
Classification System: U.S.

348/6, 10, 554, 558, 706, 724, 726, 731, 734; 455/3.2, 12.1, 63, 142, 188.1, 281, 289, 293; 375/272, 303, 304, 329, 337, 340; 329/315; 332/100

B. FIELDS SEARCHED
Electronic data bases consulted (Name of data base and where practicable terms used):

aps
search terms: c-band, frequency shift keying, (compressor or encoder), (decompressor or expander or decoder), satellite, antenna, video, modulator, demodulator, A/D converter, D/A converter

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s)1-32, is drawn to the control of the analog/digital signal receiver based upon user input control parameters, classified in class 348, 734.
Group II, claim(s) 33-35, drawn to details of the antenna re the reception of signals from a central satellite and other satellites stragetically situated around the central satellite, classified in class 455, subclass 83.
Group III, claim(s) 36, 41 and 43, drawn to a transmitting and a retransmitting system, classified in class 455, subclass 12.1.
Group IV, claims 37-40 and 42, drawn to a transmitting and/or a receiving system, classified in class 348, subclasses 724 and 726 and class 455, subclasses 142 and 293.
The inventions listed as Groups I-IV do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: Inventions I-IV are related as subcombinations as usable together in a single combination. The subcombinations are distinct from each other if they are shown to be separately usable. In the instant case, inventions I-IV have separate utility as 1) the control of a video signal receiving system to operate in one of two modes re I; 2)the antena construction so as to provide proper signal reflection from one satellite to another re II; 3) transmitting and receiving signals in a repeater system re III; and 4) separately transmitting and/or receiving video signals via satellites re IV.